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PASSAMAQUODDY FISHERIES INVESTIGATIONS, 1957-1958

REPORT TO THE INTERNATIONAL JOINT COMMISSION

SPECIAL SCIENTIFIC REPORT–FISHERIES No. 360

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

United States Department of the Interior, Fred A. Seaton, Secretary
Fish and Wildlife Service, Arnie J. Suomela, Commissioner
Bureau of Commercial Fisheries, Donald L. McKernan, Director

PASSAMAQUODDY FISHERIES INVESTIGATIONS, 1957-1958

REPORT TO THE INTERNATIONAL JOINT COMMISSION

by

International Passamaquoddy Fisheries Board

United States Fish and Wildlife Service
Special Scientific Report--Fisheries No. 360

[International Passamaquoddy Fisheries Board, 1956-1959,
Scientific Report No. 2]

Washington, D. C.
August 1960

INTERNATIONAL PASSAMAQUODDY FISHERIES BOARD

CANADA	UNITED STATES

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UNITED STATES
DEPARTMENT OF THE INTERIOR
Fish and Wildlife Service
Bureau of Commercial Fisheries
Washington 25, D. C.

January 19, 1961

ERRATA SHEET

Special Scientific Report--Fisheries No. 360 ("Passamaquoddy Fisheries Investigations, 1957-1958, Report to the International Joint Commission" by International Passamaquoddy Fisheries Board). Page ii should be as follows:

INTERNATIONAL PASSAMAQUODDY FISHERIES BOARD

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Two of the vessels used for Passamaquoddy investigations (upper) Canadian research vessel M. V. *Harengus*, (lower) United States chartered vessel M. V. *Silver Bay*.

FOREWORD

The International Passamaquoddy Fisheries Board expresses its indebtedness to the Fisheries Research Board of Canada and to the United States Bureau of Commercial Fisheries, whose staffs and consultants have played leading parts in developing its research program. The respective staffs have carried out much of the research and have coordinated investigations by others. Of cooperating agencies, the most prominent were the Markets and Economics and the Conservation and Development Services of the Canadian Department of Fisheries, the Hydrographic Service of the Canadian Department of Mines and Technical Surveys, the Economics Department of Bowdoin College, the Maine Department of Sea and Shore Fisheries, the Atlantic Sea-Run Salmon Commission, and the Woods Hole Oceanographic Institution.

The Board's special gratitude is expressed to members of the Research Committee, named on page ii, who have worked competently and faithfully.

The findings of the research group were transmitted through the International Passamaquoddy Fisheries Board to the International Joint Commission in October 1959. The extensively documented original report is now out of print; this Special Scientific Report summarizes the Committee's findings and is essentially the main report, without appendices. Individual units of research supporting this publication will appear separately in various United States and Canadian journals as numbered papers in the International Passamaquoddy Fisheries Board, 1956-1959, Scientific Report (IPFBSR) series.

CONTENTS

	Page
Foreword	iv
Introduction	1
Review of literature	4
Results of investigations, 1957-1958	5
Oceanographic studies	5
Temperature and salinity	6
Tides and tidal currents	6
Nontidal drift of surface waters	6
Flow through passages	8
Bay of Fundy and Gulf of Maine	8
Kennebecasis Bay, New Brunswick	8
Biological studies	8
Herring	8
Fishery statistics	8
Populations	10
Migrations	11
Behavior	12
Early life history	13
Plankton and food studies	14
Exploratory fishing	15
Correlation studies	16
Other species	16
Groundfish	16
Mollusks	16
Lobsters	17
Anadromous fishes	17
Miscellaneous	18
Economic studies	18
Canadian fisheries	18
Herring weir fishery	18
Herring purse-seine fishery	19
Herring carrier fleet	20
Lobster fishery	20
Groundfish fishery	20
Mollusk fisheries	20
Fish processing	21
United States fisheries	21
Herring weir fishery	21
Herring stop-seine fishery	22
Herring carrier fleet	22
Groundfish fishery	22
Lobster fishery	23
Mollusk fisheries	23
Anadromous fishes	23
Miscellaneous	23
Fish processing	23
Predictions and conclusions	24
Oceanographic effects of impoundment	24
Water levels	25
Currents	26

Page

Water temperatures 26
Salinity 26
Oxygen content 27
Biological effects of impoundment 27
Herring 27
Groundfish 29
Mollusks 29
Lobsters 29
Anadromous fishes 30
Other species 30
Economic effects of impoundment 30
Primary fishing industry 30
Secondary fishing industry 32
Recapitulation 33
Summary 37
Literature cited 39

FIGURES

Frontispiece: Two of the vessels used for Passamaquoddy investigations. iii
1. Map showing location of high pool, low pool, filling gates, emptying gates, and powerhouse. The Quoddy Region is shown in inset 2
2. Average annual landings of herring and other species in the Quoddy Region. High-pool, low-pool, and outside-area landings are superimposed in their respective positions 3
3. Seasonal variations in temperature and salinity of surface and bottom waters in the inshore and offshore areas of the Quoddy Region 6
4. Surface tidal currents in the Quoddy Region showing half-ebb and half-flood conditions 7
5. Total (Canadian and United States) herring landings in the high and low pools and in the part of the Quoddy Region outside the proposed dams 9
6. Comparison of length-frequency distributions of herring samples collected in the Passamaquoddy region during the month of September in 1915, 1932, 1957, and 1958 11
7. Major Bay of Fundy and Gulf of Maine herring groups as determined by serological and parasitological methods 12
8. Movements of herring as shown by tagging. The straight lines connect the areas of tagging to points of recovery but do not show lines of travel 13
9. Underwater television camera, and holding cage, used for herring behavior experiments 14
10. Rotating tank used to measure the swimming speeds of herring 15
11. Spawning areas, distribution and abundance of herring larvae, and surface currents in the Bay of Fundy and Gulf of Maine, during the autumn 16
12. Relative abundance of plankton inside and outside Passamaquoddy and Cobscook Bays. Only forms which constitute food for herring are included 17
13. Typical Canadian weirs. In the foreground, a simple weir without a parlor. In the background, a compound weir with a parlor in which herring are held alive awaiting sale 19
14. Approximate locations of Canadian and United States herring weirs operated in the Quoddy Region in 1957 19
15. Typical United States stop seine. In the background, note the pocket for removing the herring "sardine" catch 21
16. United States herring carriers 22
17. A United States sardine cannery 23

Page

18. Daily cycle of power project operations showing the variation in water level for the high pool, low pool, and outside areas. Periods when filling and emptying gates are open are also shown 24
19. Schematic illustration of elevations and ranges of water levels in the high pool, low pool, and outside areas for spring, mean, and neap tides 25
20. Depth distribution of herring schools in Passamaquoddy Bay as determined by sonic-sounder recordings (upper) day, (lower) night 28

PASSAMAQUODDY FISHERIES INVESTIGATIONS, 1957-1958

by

International Passamaquoddy Fisheries Board

INTRODUCTION

In 1956, the Governments of Canada and the United States asked the International Joint Commission to determine whether the tidal forces of Passamaquoddy and Cobscook Bays could be used to produce hydroelectric power, and to appraise the effect of powerdam construction on the important fish and shellfish industries of the area. Two Boards were established on October 3, 1956: the International Passamaquoddy Engineering Board, which was charged with a study of the engineering aspects of the proposed project, and the International Passamaquoddy Fisheries Board, which was made responsible for a study of fisheries that might be affected by the project. The specific reference to the International Passamaquoddy Fisheries Board was--

> . . . to determine the effects, beneficial or otherwise, which such a power project might have on the local and national economies in the United States and Canada, and, to this end, to study specifically the effects which the construction, maintenance, and operation of the tidal power structure proposed might have upon the fisheries in the area. . . (Cf., I. J. C. Docket 72, October 3, 1956.)

The first regular meeting of the Fisheries Board took place on November 16, 1956. Thereafter regular meetings were held semiannually. Informal meetings were also held immediately before International Joint Commission hearings in April and October each year.

The Board appointed a research committee of Canadian and United States scientists to develop plans and to conduct the necessary research on the fisheries of the Passamaquoddy Region.

A joint engineering and fisheries committee of the Engineering and Fisheries Boards was set up in accordance with directions from the International Joint Commission dated October 4, 1957. The Joint Engineering and Fisheries Committee assured that no aspects of the Passamaquoddy problem would be overlooked, established an appropriate and practicable line of demarcation between the work of the two Boards, and attempted to obtain uniformity in measuring benefits and damages.

At its second meeting, held in Boston, Mass., on March 6, 1957, the Board approved a research program to provide as much pertinent information about the area and its fisheries as could be expected within the time limits imposed and the money appropriated. It recognized, however, that such short-term studies could not answer all of the questions that had been raised.

The research program considered not only the "sardine" herring fishery, but also the fisheries for cod, haddock, flounder, redfish, hake, pollock, salmon, alewives, clam, smelt, scallops, and lobsters. All of the fisheries were certain to be affected in some way by the proposed structures. The principal problems concerned the sources of fish, method of transport to the fishing grounds, the environmental conditions within Passamaquoddy and Cobscook Bays and their approaches, and the commercial value of recent catches.

The investigations extended to all parts of the Bay of Fundy and the Gulf of Maine

Figure 1.--Map showing location of high **pool**, **low pool**, filling gates, emptying gates, and powerhouse. The Quoddy Region is shown in inset.

where proposed structures might reasonably be expected to affect fish populations. Particular emphasis, however, was placed on the Quoddy Region, which was defined as the area inside a line drawn from Point Lepreau, N. B., to Northern Head, Grand Manan, N. B., thence to West Quoddy Head, Maine. The Region was divided by the proposed dams into high-pool, low-pool, and outside areas on the basis of information received from the International Passamaquoddy Engineering Board in October 1957. A study of the gross features of the Kennebecasis Bay area, near St. John, N. B., was made because it had certain physical aspects which were similar to those that would be imposed upon the Passamaquoddy area if power dams were constructed.

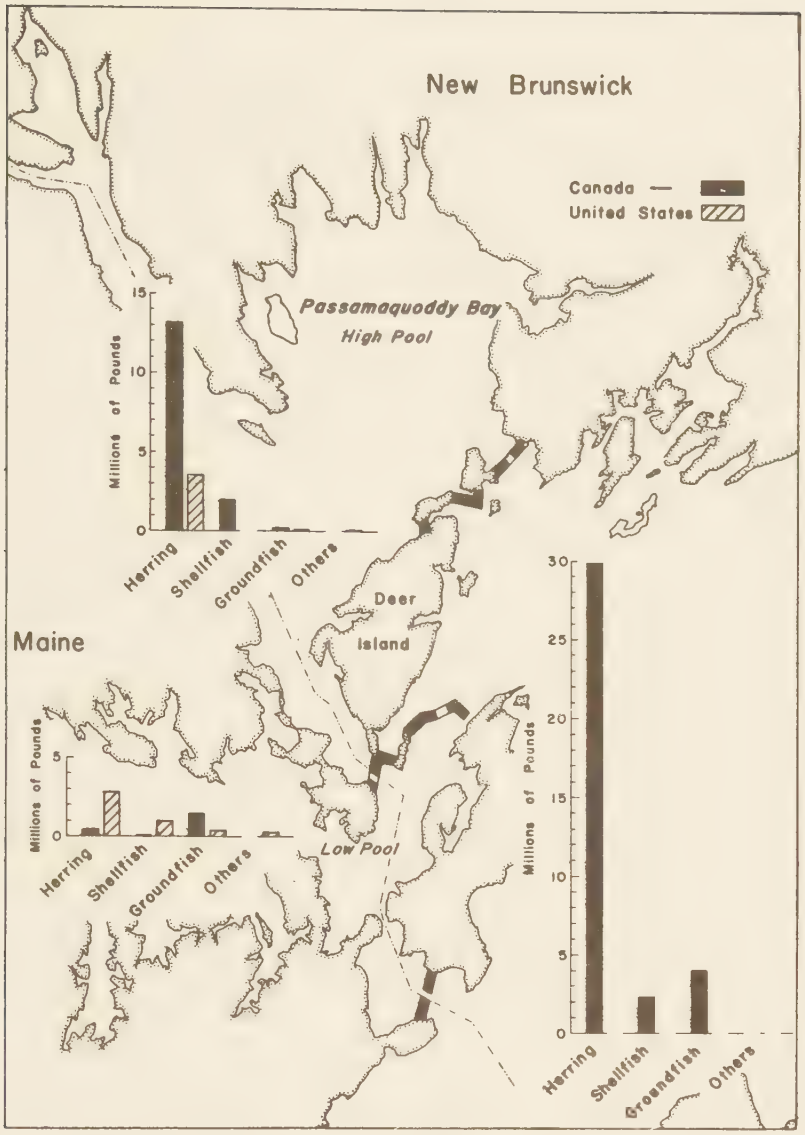

Figure 2.--Average annual landings of herring and other species in the Quoddy Region. High-pool, low-pool, and outside-area landings are superimposed in their respective positions.

Construction of an hydraulic model for hydrographic studies and for studies related to fish behavior was considered, but was ruled out because the anticipated additional information would not justify the cost. Special attention was given to the problem of assuring facilities for passage of anadromous fishes from the open sea to their spawning grounds in the rivers and lakes.

To establish a basis for prediction of the effects of the dams on fisheries, the present oceanographic, biologic, and economic features of the area and its fisheries were studied. Temperature, salinity, tides, and tidal currents in the bays, in the approaches, and outside the bays were studied. Biological studies were made of fish populations, breeding grounds, nursery areas, food and feeding habits, and the interrelationship of fish and their environment. Economic studies of the capital value of fishing and processing equipment, of fishing receipts and costs, and of the general economic environment of the area were also undertaken.

The research program was carried on as a cooperative effort by the Fisheries Research Board of Canada and the United States Bureau of Commercial Fisheries.

Some projects within the program were assigned to other organizations. Studies of herring behavior, migrations, length, age, vertebral counts, spawning areas and seasons, distribution of larvae, explorations, and compilations of catch statistics were carried out both at St. Andrews, N. B., and at Boothbay Harbor, Maine, laboratories. Parasitological and serological projects were done at the Boothbay Harbor laboratory; plankton and correlation projects, at the St. Andrews laboratory. Specialists from Canada and the United States were consulted on the biology of other species. A survey of fish-passage needs was carried out by fishery engineers of the Canadian Department of Fisheries and the United States Bureau of Commercial Fisheries.

The Atlantic Oceanographic Group of the Fisheries Research Board of Canada carried out studies of circulation and distribution of physical properties in the Quoddy Region and an oceanographical and biological reconnaissance of the Kennebecasis area. The study of nontidal drift in the Bay of Fundy and the Gulf of Maine was the responsibility of the Woods Hole Oceanographic Institution, which operated under a contract with the United States Bureau of Commercial Fisheries. The tide and tidal-current project was done jointly by the Atlantic Oceanographic Group and the Hydrographic Service of the Department of Mines and Technical Surveys of Canada.

Economic surveys of herring and lobster fisheries in southern New Brunswick were carried out by the Economics Service of the Department of Fisheries of Canada. The United States Bureau of Commercial Fisheries, assisted by economists from Bowdoin College, made an economic survey of the Maine "sardine" fishery. The Fisheries Research Board of Canada provided assessments of probable effects on other species in the Canadian area. The Maine Department of Sea and Shore Fisheries, under a United States Bureau of Commercial Fisheries contract, provided a comparable service for the United States.

REVIEW OF LITERATURE

Comprehensive and valuable information on the Passamaquoddy area and its fisheries is contained in the literature. This information was carefully considered, particularly during the planning and final-assessment stages of the present investigations.

One of the earliest systematic oceanographic surveys in the Bay of Fundy consisted of tidal-current measurements by Dawson (1908). Extensive data have been collected since that made possible a general description of the nontidal circulation and the spatial and temporal distribution of temperature and salinity. Copeland (1912), Craigie (1916), Vachon (1918), Hachey (1934b), Watson (1936), and Bailey (1957) dealt with certain oceanographic aspects of Passamaquoddy Bay. Studies of oceanographic features of the Bay of Fundy were published by Craigie and Chase (1918), Mavor (1922, 1923), Hachey (1934a, 1935), Watson (1936), Fish and Johnson (1937), McLellan (1951), MacGregor and McLellan (1952), Ketchum and Keen (1953), and Bailey et al. (1954). Hachey (1957) reviewed oceanographic requirements relative to the sardine fishery in the Passamaquoddy area.

Studies of the effects of dams on the fisheries of the Passamaquoddy area were first conducted during the late 1920's and early 1930's. In February 1928, Dr. A. G. Huntsman, Director of the Atlantic Biological Station at St. Andrews, N. B., testifying before a Royal Commission on Maritime Fisheries, predicted considerable damage, particularly to herring, clam, and pollock fisheries. Huntsman (1928) predicted the elimination of the important fisheries of Passamaquoddy Bay and serious effects on fisheries of neighboring areas as far away as Digby County in Nova Scotia and along the coast of Maine.

On June 2, 1928, at a meeting of the North American Council on Fishery Investigations, the question of the effects of the Passamaquoddy project on international fisheries was raised, and a resolution passed urging the Governments of the two countries to carry out detailed investigations. The International Passamaquoddy Fisheries Commission was set up in 1931 to carry out necessary studies. Field work was completed during the summer of 1933, and in October of the same year a final report was presented.

The conclusions given in the report were as follows:

> The physical effects of the present mixing mechanism appear to be local and although the construction of the dams would influence the hydrographic conditions in the passages, it is not expected that their influence would extend far into or beyond the Outer Quoddy Region.
>
> The influence of this local mixing on the supply of nutrient salts in the surface layers, where they are available for plant production, is almost entirely confined to the Quoddy Region. The conditions existing over the greater part of the Bay of Fundy appear to result from other factors, which would not be influenced by the dams. It is not considered that the construction of the dams would have an appreciable effect upon the production of plant life outside the Quoddy Region.
>
> The rich fishery in the Quoddy Region is not due to a localized abundance of zooplankton. The zooplankton supply which supports the herring population outside of Passamaquoddy Bay in summer (and is found within the bay in winter) is considered to be mainly produced in areas beyond the influence of the Quoddy mixing mechanism and transported passively by ocean circulation into the region. Any influence of the proposed dams upon this supply would probably be insignificant.
>
> A sure forecast of the effect of the proposed dams on the fishery requires more comprehensive and more detailed knowledge of the biology of the herring than is available at present. The researches do, however, lead to some relevant conclusions.
>
> The herring population is produced beyond the influence of local mixing and no way has been foreseen by which the dams would render the Outer Quoddy Region or the Bay of Fundy less favorable to the existence of herring arriving from elsewhere.
>
> The effect upon the availability of herring is likely to be considerable. Many changes in the set of tidal streams may be expected, and probably every little change would have an effect on the fishery of nearby weirs. Some weirs would be made richer, some poorer. It cannot be foretold whether the total effect of disturbance of tidal streams on capture outside of the dams would be deleterious or not.
>
> There appears little probability of the proposed dams affecting the sardine fishery along the coast of Maine or even seriously at Grand Manan.
>
> The herring fishery inside of Passamaquoddy Bay would almost certainly be reduced to negligible proportions. (North American Council on Fishery Investigations, Proceedings 1931-1933, No. 2, 1935, pp. 6-7.)

Other biological investigations in the Bay of Fundy and adjacent areas included studies of herring spawning areas and seasons by Perley (1852), and Bigelow and Schroeder (1953). Graham (1936), and Fish and Johnson (1937) discussed the distribution of herring larvae. Moore (1898), Battle (1935), Battle et al. (1936), and Johnson (1940) described the food and feeding habits of herring. Huntsman (1934, 1952, 1953), Battle et al. (1936), and Graham (1936) considered the influence of environmental conditions on the movements and catches of herring. Leim (1956) prepared an annotated bibliography of Bay of Fundy herring and Scattergood (1957) published a bibliography of Atlantic and Pacific herring.

RESULTS OF INVESTIGATIONS, 1957-1958

The reference from the International Joint Commission specified that an economic assessment be made of any changes in the fisheries which might result from the proposed tidal power project. Such an assessment depends on a forecast of the probable effects on abundance and availability of fish and other organisms. This, in turn, depends on prediction of changes in the physical environment. Hence, the logical sequence for presenting the results of investigations is (1) oceanography, (2) biology, and (3) economics.

OCEANOGRAPHIC STUDIES

The Quoddy Region and contiguous areas of the Bay of Fundy and Gulf of Maine were studied to determine present circulation, tides, distribution of properties, and controlling or relating factors, and to predict changes that may occur if dams are installed. To assess present conditions, extensive measurements and observations were made during 1957 and 1958, together with data gathered from the region over a period of 50 years prior to 1957.

Oceanographic features of the Bay of Fundy are determined by tide-producing forces, the earth's rotation, river discharge, meteorological conditions, and bottom configuration. Due to strong tidal currents (up to 8 feet per second) vertical mixing proceeds vigorously; hence, seasonal fluctuations in temperature and salinity are much reduced. Circulation in the main portion of the Bay is anticlockwise. Inflowing waters hold close to the Nova Scotia coast. Outflowing waters pass along the southeastern coast of Grand Manan, thence along the coast of Maine or across the mouth of the Bay to Nova Scotia.

Temperature and salinity

Mean annual ranges in temperature and salinity of the surface layer in the Quoddy Region are approximately 34° to 54° F. and 30 to 33 parts per thousand. Seasonal variations in inshore areas and in Passamaquoddy Bay are slightly greater than in offshore areas. During 1957 and 1958, 43 cruises were completed in the Quoddy Region. They covered a network of stations, in which temperature and salinity were observed and drift bottles released.

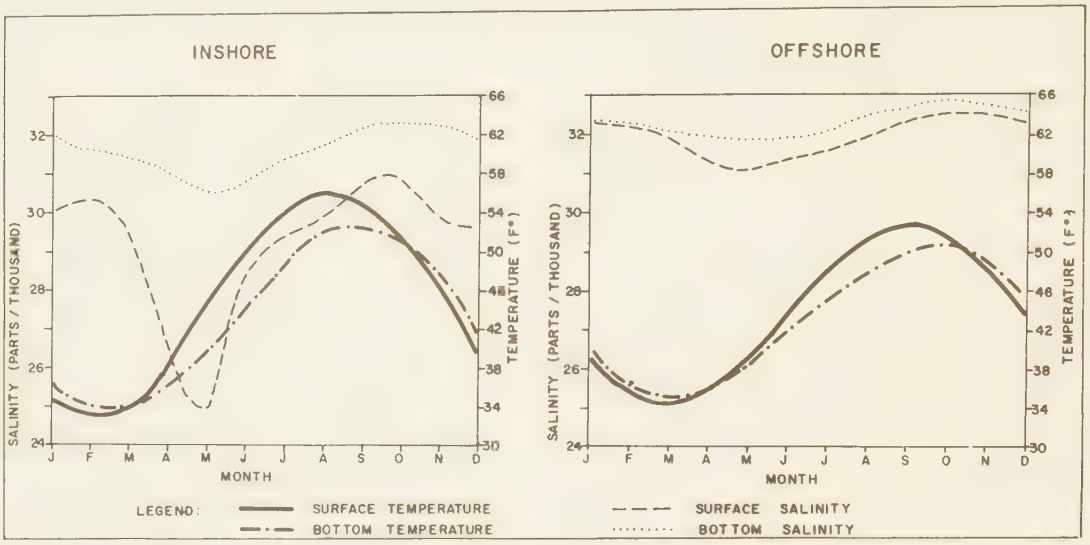

Figure 3.--Seasonal variations in temperature and salinity of surface and bottom waters in the inshore and offshore areas of the Quoddy Region.

Oceanographic features in the 2 years were very different. This difference has been related, in part, to abnormal river runoff, which was well below normal in 1957 and well above normal in 1958. The flushing time (i.e., the average length of time required to remove 1-day's contribution of river water) for Passamaquoddy Bay varied from about 8 to 20 days, with the more rapid flushing rate occurring during high river discharge.

Tides and tidal currents

Currents were measured at 60 stations in Passamaquoddy Bay and the Bay of Fundy during the summers of 1957 and 1958. This project was carried out jointly by the Canadian Hydrographic Service of the Department of Mines and Technical Surveys and the Atlantic Oceanographic Group of the Fisheries Research Board of Canada. The program was aimed at determining the tidal and nontidal water movements in Passamaquoddy Bay and its approaches and in part of the Bay of Fundy.

Tides in the Bay of Fundy are characterized by a predominant semidiurnal component. Tidal amplitude in the Quoddy Region varies from an extreme minimum of approximately 14 feet at neap tide to a maximum of nearly 28 feet at spring tide. The mean tidal range is approximately 20 feet. Tidal currents vary markedly throughout the Region. Maximum recorded speeds were found in Letite Passage where mean maximum speeds reached 8 feet per second (4.8 knots). In Passamaquoddy Bay, speeds were mostly less than 1 foot per second. Near the mouth of Cobscook Bay, mean maximum speeds were 5 feet per second. In the outside area, mean maximum speeds seldom exceeded 5 feet per second. Currents were usually maximum in the surface layer and decreased slowly with depth. Residual flows were mostly less than 2 miles per day in Passamaquoddy Bay, Cobscook Bay, and the approaches. In the Bay of Fundy, residual flows were variable and in some areas were as much as 10 miles per day.

Nontidal drift of surface waters

During 1957 and 1958, approximately 10,000 drift bottles were released in the

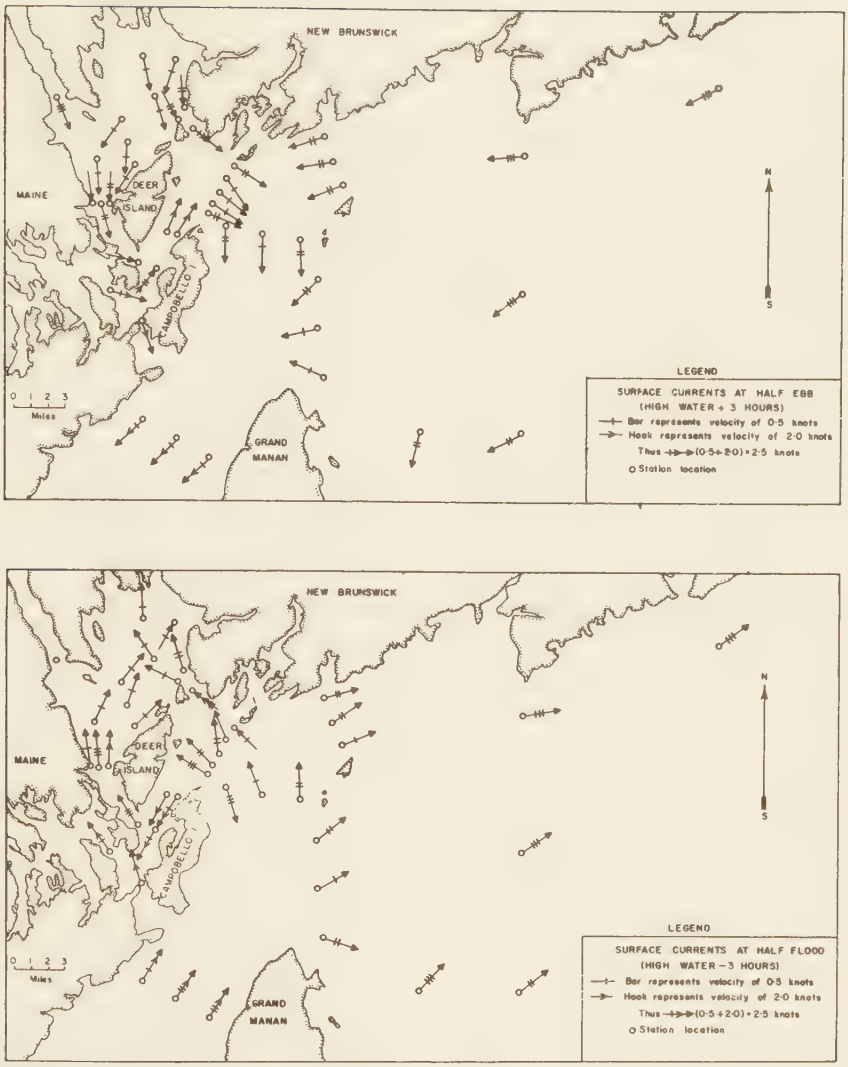

Figure 4.--Surface tidal currents in the Quoddy Region showing half-ebb and half-flood conditions.

Quoddy Region and about 25 percent were recovered. During the first 10 days, 9 percent were recovered, and during the first 30 days, 17 percent. Inside Passamaquoddy Bay, in Cobscook Bay, and in the Passages, the usual distance between release and recovery was of the same order of magnitude as the tidal excursions. Hence, it is difficult to infer net circulation in this area. Inside Passamaquoddy Bay, surface circulation on the average appeared to be counterclockwise; however, wind evidently modified this situation markedly. On the whole, wind action is very effective in moving the surface layer. In general, winds with a southerly component tend to confine surface waters to Passamaquoddy Bay, while winds from the north and west remove surface waters from the Bay. In each instance, there must be compensating flow at subsurface levels. No clear picture of net surface flow through Letite and Western Passages was established. There is some evidence that, on the average, net flow is outward through Western Passage and inward through Letite Passage. However, there are instances when net flow appears to be reversed. There also are times when surface flow is in the same direction in both passages with a compensating subsurface flow. Drift-bottle returns plotted on a monthly basis indicate marked changes in pattern of flow both seasonally and for the same month for the 2 years. A small percentage of the drift bottles leave the region; some move along the coast of Maine as far as Massachusetts,

while others drift across the Bay of Fundy to Nova Scotia.

Flow through the passages

The electromagnetic induction method of measuring water transport was used in Western and Letite Passages, Lubec Narrows, and the Saint Croix estuary. The average duration of the flooding tide into Passamaquoddy Bay is approximately 6 hours, while the tide ebbs for nearly $6\frac{1}{2}$ hours. Tidal currents during the flood are slightly higher than during the ebb. In Western Passage, slack water occurs later than in Letite Passage. This phase lag varies from 15 to 50 minutes with some degree of periodicity. Evidence indicated that residual flow, while seldom very pronounced, was on the average outward through Western Passage.

Bay of Fundy and Gulf of Maine

Considerable attention was given to the oceanography of the Bay of Fundy and the Gulf of Maine. Returns from 35,000 drift bottles launched in the Gulf of Maine area since 1919 were examined to determine the sources of surface waters that enter the Bay of Fundy. The area from which drift bottles enter the Bay is restricted during January to the immediate approaches to the Bay. This area gradually expands during the spring to a maximum in early summer when it encompasses most of the Gulf of Maine and part of Georges Bank. The source area gradually retracts during autumn to the eastern side of the Gulf of Maine and northward away from Georges Bank. Thus, there is little likelihood that herring larvae spawned on Georges Bank in the autumn would drift into the Bay of Fundy. There is some evidence that a sudden increase in runoff gives impetus to increased circulation out of the Bay of Fundy and along the Maine coast to Massachusetts Bay. From January to March, 1958, there was marked movement down the coast of Maine; bottles reached Cape Cod in as little as 3 weeks after release in the Quoddy Region. This occurred during and following a period of high river runoff. During 1957, a period of drought, few drift bottles launched in Passamaquoddy Bay were recovered outside the Bay of Fundy.

Kennebecasis Bay, New Brunswick

A study was made of Kennebecasis Bay and the Saint John estuarial system, since physical and biological conditions in Kennebecasis Bay seemed similar to those expected in Passamaquoddy Bay if dams were installed. Results of the study showed a degree of similarity between Kennebecasis Bay and Passamaquoddy Bay when dammed. There are two important factors, however, that are markedly different for the two situations. One is that quantities and relative locations of fresh water discharged into the two areas differ. The other is that two sills separate the saline water of the Bay of Fundy from the deep water in Kennebecasis Bay, compared with one sill under the proposed conditions for Passamaquoddy Bay. Therefore, distribution of properties in Kennebecasis Bay represents a more extreme condition than is anticipated in Passamaquoddy Bay if power dams are installed. The results of this study are useful in estimating the extreme conditions probable in Passamaquoddy Bay after impoundment.

BIOLOGICAL STUDIES

The primary aim of biological studies was to provide information on abundance, distribution, habits, and reproduction of fish stocks in the Quoddy Region. Results apply particularly to herring, but consideration was given to other species of commercial importance in the region and ways they would be affected by the dams. Species not present in commercial quantities now, but which might increase under new conditions, were also considered as were species present in quantity but not of current commercial interest.

Herring

Fishery statistics.--Herring landing statistics for southern New Brunswick and eastern Maine are not available before the latter part of the 19th century when the fishery was chiefly for large, mature fish. Canadian landings of these fish declined from about 25 million pounds in the 1880's to less than 5 million pounds in the 1920's. Over the same period, catches of small, immature "sardine" herring increased from about 5 million pounds to nearly 70 million pounds. During the last 20 years, Canadian and United

States landings in the Quoddy Region have consisted almost entirely of sardine herring and, while there have been large year-to-year fluctuations, average landings have been about 55 million pounds annually.

Weirs are the most important method of capture, but stop seines and purse seines are becoming more popular and are accounting for increasing proportions of the total herring catch. The fishery is seasonal and most of the landings are made during the summer. Sardine canning is the major market for herring, but substantial quantities are canned as pet food and reduced to meal and oil. Pearl essence is an important and valuable byproduct.

A survey was made of the herring fishery in southern New Brunswick. Landings by counties and areas from 1920 to 1958 were examined. Annual and monthly landings by fishery statistical areas in southern New Brunswick for 1937 to 1958 were studied in detail. During 1957 and 1958, daily catch statistics were collected according to individual units of gear. Interviews with weir owners provided catch records for 1947 to 1957. Because the proposed dams will divide the Region into pools which will not coincide with existing fishery statistical districts, the data were used as a basis for allocating recent catches to the new pool areas.

The average annual herring landings in the high pool from 1947 to 1958 were 13,200,000 pounds; in the low pool, 500,000 pounds; immediately outside the dams (Head Harbour to Deadman Head) 13,400,000 pounds; in the remainder of the Quoddy Region, 16,400,000 pounds; and in the remainder of southern New Brunswick, 26,500,000 pounds.

In the Quoddy Region, west of Letite Passage, 70 to 75 percent of the catch is landed from June to September; however, east of Letite Passage where there is a large winter purse-seining fishery, about 54 percent of the landings are made during these months.

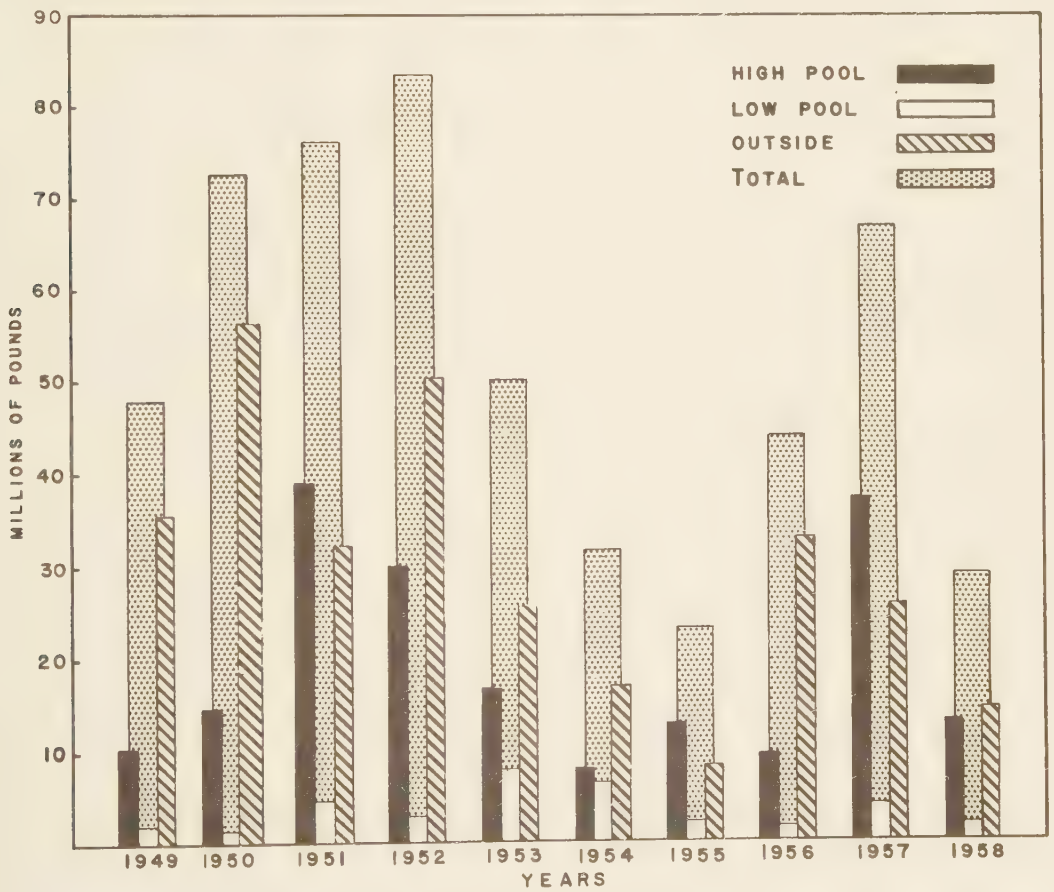

Figure 5.--Total (Canadian and United States) herring landings in the high and low pools and in the part of the Quoddy Region outside the proposed dams.

Before 1957, there were no detailed records of landings by gear. Though there are almost 1,100 registered weir sites in Charlotte and Saint John Counties, only a small proportion are licensed annually. During 1957 and 1958, weirs caught 70 to 85 percent of the catch in the two counties. The balance was made by drag or stop seines (5 to 7 percent) and purse seines (9 to 22 percent).

From 1947 to 1958, the number of weirs built and operated varied from 56 to 85 in the high pool, from 9 to 21 in the low pool, and from 111 to 205 in the remainder of the Quoddy Region. Over the same period, the average catch per weir was about 240,000 pounds in the two pools, while in the outside area it was approximately 130,000 pounds.

Detailed information on the Maine herring fishery was available from the daily catch records that have been collected since 1947. From these records, statistics of the fishery by weeks, months, areas of capture, and gear were compiled. Certain facts pertinent to the Passamaquoddy studies are evident. In the past 12 years, the total Maine catch varied from 75 to 200 million pounds, while that of the Quoddy Region varied from 2 to 11 million pounds or from 1 to 12 percent of the total. However, the processing industry does not depend solely on herring taken locally, but draws upon Canadian Quoddy and other areas of Maine, New Brunswick, and Nova Scotia.

Many marked fluctuations are noted from the statistics. For example, in 1947, the low-pool catch was 49,000 pounds, and the high-pool catch 6,273,000 pounds; in 1954, the low-pool catch was 6,369,000 pounds; and the high-pool catch 238,000 pounds. The average high-pool catch from 1947 to 1958 was 3,613,000 pounds, and the low-pool catch 2,878,000 pounds. In the high pool, weirs caught 82 percent of the herring landed; stop seines took the remainder. In the low pool, stop seines caught about 77 percent of the herring, and weirs about 23 percent. Since 1947, the number of weirs in operation in both pools has varied from 14 to 31. Weirs in the low pool have fluctuated markedly: from none to 16. In 1958, there were 10 weirs in the high pool and 4 in the low.

From 1947 to 1958, Maine herring landings immediately outside the dams (from West Quoddy Head to Cross Island) averaged 6,121,000 pounds, and the remainder of Washington County (from Cross Island to Gouldsboro) 28,134,000 pounds. In 1958, there were 59 weirs between West Quoddy Head and Gouldsboro and these accounted for 64 percent of the catch; stop seines took the remaining 36 percent.

The herring fishery is seasonal. Ninety percent of Maine landings and 94 percent of Washington County landings are made from June through October. Landings in the high pool are greatest from August through October and in the low pool, from September through October.

Populations.--Population studies included an analysis of data on length and age composition, year-class variation, and growth, collected in the Quoddy Region in 1957 and 1958. Studies of parasites and reactions of blood components were made from 1955 through 1958 including samples from the entire Atlantic area from Newfoundland to New Jersey.

Length and age analyses were based on 71,000 herring sampled for length and 23,000 fish sampled for scales. All samples were drawn from the commercial fishery for immature herring. Determinations of age and growth were made by length-frequency analysis because a high proportion of the scales were unreadable. The fishery is sustained by herring which grow to a length of between $4\frac{1}{4}$ and 5 inches in their first year of life and to a length of between $6\frac{1}{4}$ and $7\frac{1}{2}$ inches in their second year. This growth is in agreement with results of investigations made in 1915 (Huntsman 1919) and 1932 (Graham 1936).

Studies of parasites and serological reactions show that adult herring spawning off the Nova Scotia coast are distinguishable from those spawning on Georges Bank. Immature herring from the Gulf of Maine are distinguishable as two subgroups--"eastern" and "western"--with a zone of mixing in the vicinity of Penobscot Bay. The "eastern" subgroup showed greater serological similarity to southwest Nova Scotia adults than to Georges Bank adults. This similarity suggests that spawning off the Nova Scotia coast is principally responsible for eastern sardine stocks, including those of the Quoddy Region.

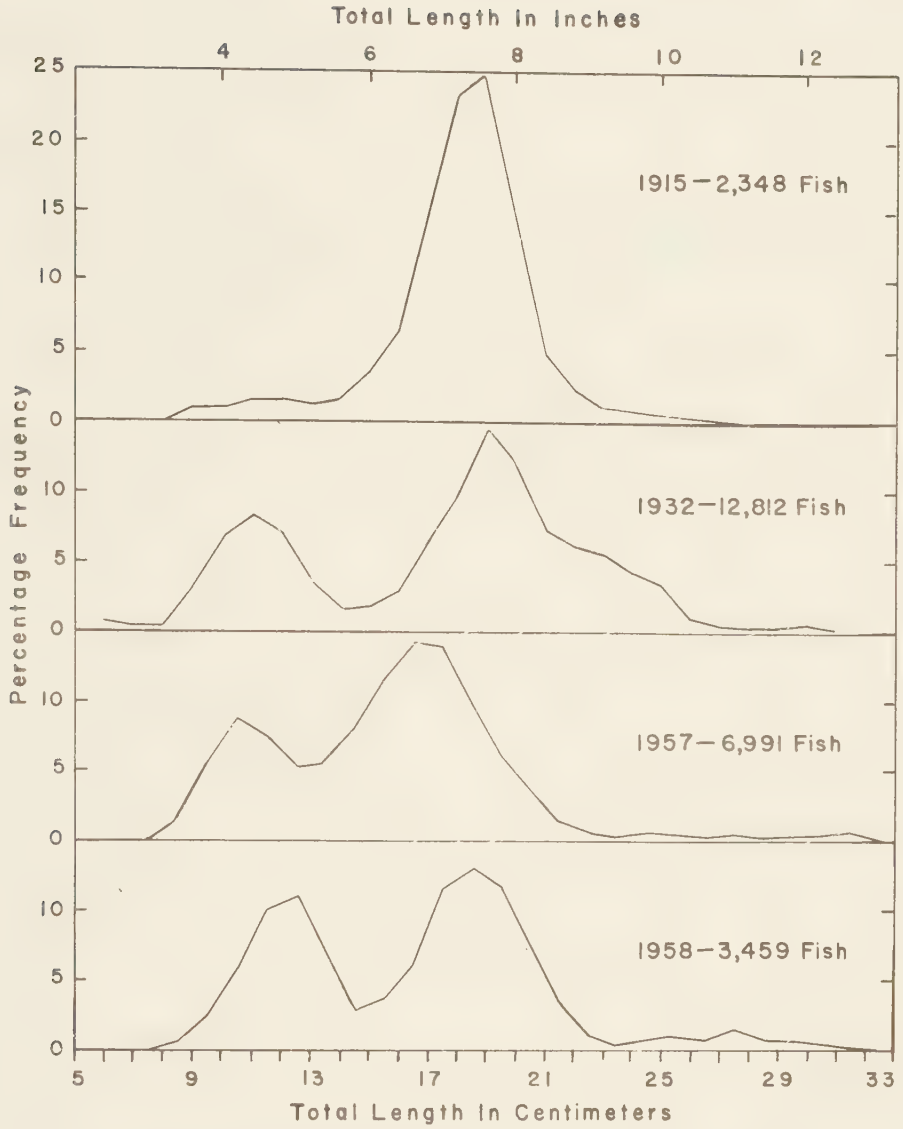

Figure 6.--Comparison of length-frequency distributions of herring samples collected in the Passamaquoddy Region during September in 1915, 1932, 1957, and 1958.

Migrations.--Movements of herring in and near the Quoddy Region were studied to discover the source and the fate of the herring in Passamaquoddy and Cobscook Bays. In 1957 and 1958, 59 taggings involved more than 137,000 herring. Recaptures from 1957 taggings totalled 792 (2.1 percent) while recaptures from 1958 taggings totalled 2,790 (2.8 percent).

Recaptures showed that herring move in and out of Passamaquoddy Bay from points as far east as Point Lepreau and as far south as southern Grand Manan. No recaptures from Passamaquoddy Bay taggings were made to the southwest along the coast of Maine. However, some fish tagged on the coast of Maine moved to Passamaquoddy Bay and beyond to Point Lepreau. The pattern of recoveries did not indicate clearly whether movements were via Letite or Western Passage, but there was some indication that both passages were used. Comparison of drift-bottle and tag recoveries indicated that herring do not always move in the same direction as the surface currents. While there is insufficient information to establish a pattern of herring migrations, there is a suggestion of random movement.

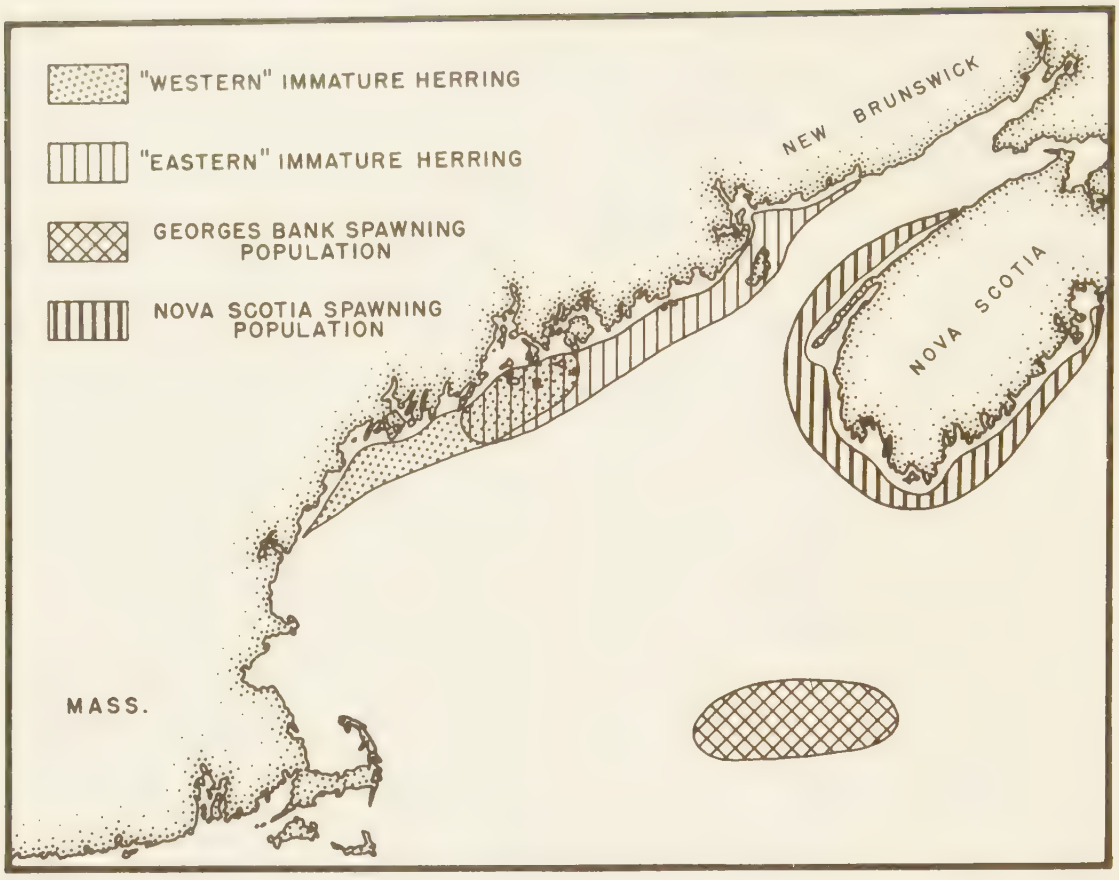

Figure 7.--Major Bay of Fundy and Gulf of Maine herring groups as determined by serological and parasitological methods.

Results demonstrate that there is no mass movement of herring away from the Quoddy Region from April to November. Because the tags remained on the fish for short periods, no information was obtained on movements into or away from the Region during the winter months.

Behavior.--To determine whether herring could withstand anticipated changes in hydrographic conditions in Passamaquoddy and Cobscook Bays, temperature, salinity, and pressure tolerances were investigated. The behavior of herring in currents, their swimming speeds, and depth distribution provide a basis for prediction of fish movements in the approaches to the dams and the turbines.

Mortalities of herring at various temperatures were determined for newly caught fish. Large herring were more acutely affected by high temperatures than were small herring. The temperature at which 50 percent of the herring would die in 48 hours was calculated to lie between 66° and 70° F. for $3\frac{1}{2}$- to 12-inch herring.

The tolerance of herring to various salinities was tested, and it was found that salinities as low as 5 parts per thousand are not injurious.

Resistance of herring to rapid changes in pressure was investigated to determine whether they could survive the pressure changes encountered during passage through the turbines. Sardine herring accustomed to surface pressure withstood an increase of 67 pounds per square inch (equivalent to a water depth of 150 feet) at a rate of 0.8 pounds per square inch per second. Sardines accustomed to a pressure of 20 pounds per square inch survived decompression at a rate of

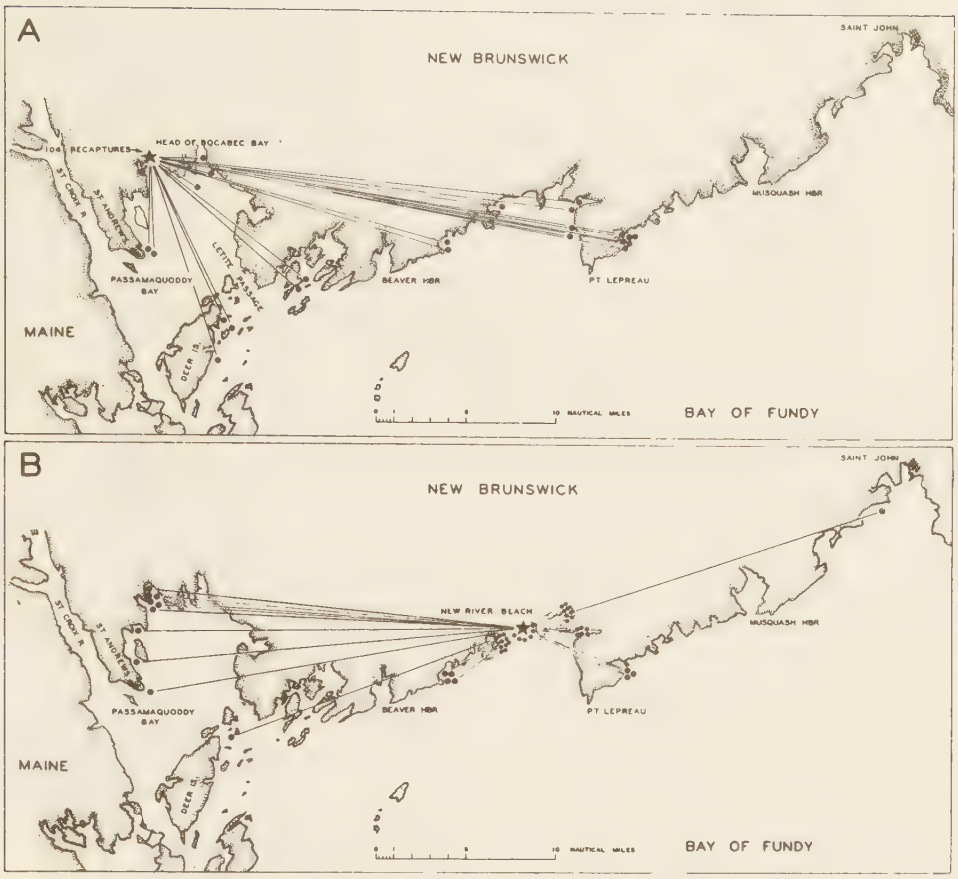

Figure 8.--Movements of herring as shown by tagging. The straight lines connect the areas of tagging to points of recovery but do not show lines of travel.

12.5 pounds per square inch per second. Predicted pressures and rates of pressure change between turbine intakes and exits are therefore within the limits which these fish can withstand. The effect of increase in pressure from the top of the draft tube to its lowest point was not investigated but anticipated pressure changes are unlikely to injure the fish.

Herring held in a large mesh-covered cage responded to the movement of water through the cage by heading into the current and swimming from side to side in the "upstream" direction. The response seemed to be based on visual stimuli, but its effectiveness was limited by the maximum swimming speed. With increasing water velocities, herring continued to swim against the current until forced backward, tail first. Swimming speeds increased with size of fish and ranged from 2.4 to 4.7 feet per second (1.4 to 2.8 knots) for herring with mean lengths of $2\frac{3}{4}$ to $10\frac{1}{2}$ inches. Swimming endurance also increased with size of fish. Herring $7\frac{3}{4}$ inches long were able to stem currents of 3.4 feet per second for a period of 13 minutes.

Examinations of echo-sounder records showed that during the fishing season from May to October the median depth of herring shoals varied from 26 to 35 feet during the day and from 17 to 23 feet at night.

Early Life History.--There were 33 cruises (1,404 plankton tows) from September 1956 to February 1959 throughout the Bay of Fundy and Gulf of Maine to study distribution and abundance of herring larvae as indicators of spawning grounds and nursery areas, and to discover survival, growth, and methods of transport of herring to the Passamaquoddy area. There were two main spawning grounds:

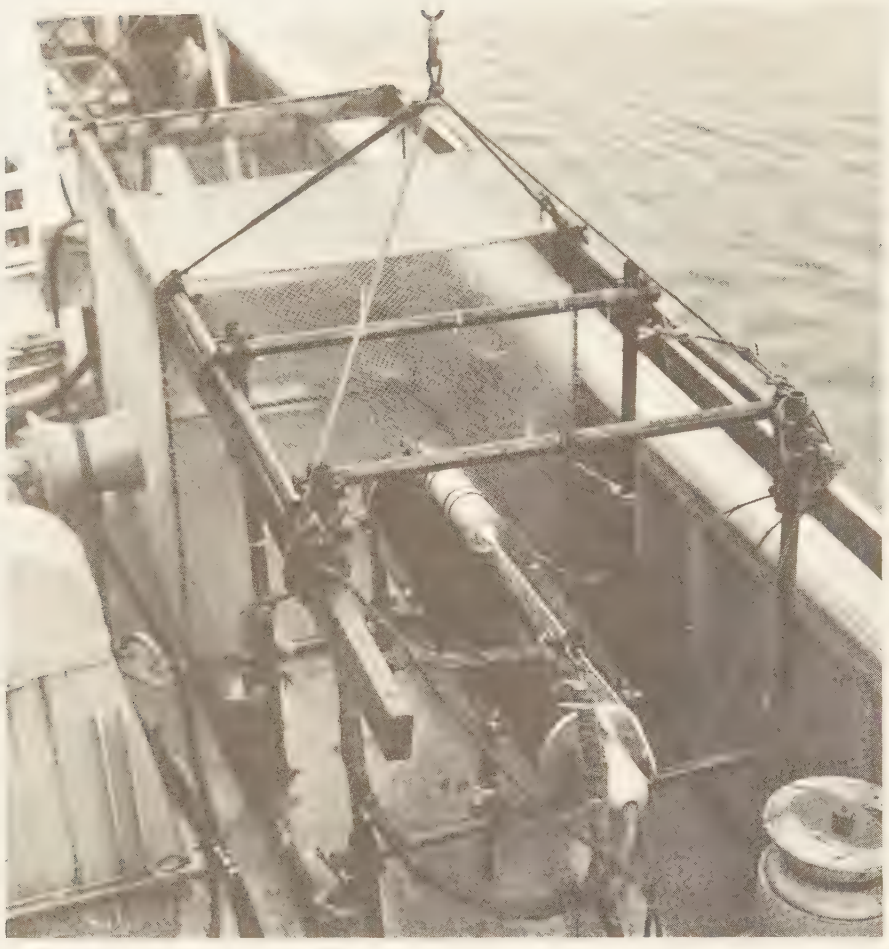

Figure 9.--Underwater television camera and holding cage used for herring behavior experiments.

the northern edge of Georges Bank and the southwest Nova Scotia coast. Catches of newly hatched larvae indicated small spawnings in Penobscot Bay, on Stellwagen Bank, on Nantucket Shoals and south of Grand Manan. There was no evidence of spawning inside Passamaquoddy or Cobscook Bays. Large numbers of herring larvae were found on Georges Bank and in the Bay of Fundy in September and October each year. Catches decreased sharply in November and were very small in December, January, and February except for one large catch in December 1956. Only occasional specimens were taken in other months.

The drift of larvae, as indicated by distribution of larger larvae and by nontidal surface currents in the Bay of Fundy and Gulf of Maine, suggested that southwest Nova Scotia spawnings are major contributors to commercial stocks of herring in inshore areas of southern New Brunswick and eastern Maine. Other spawnings, particularly those on Georges Bank, may also supply some herring to the area.

Plankton and food studies.--Data from 2,537 plankton tows in the Quoddy Region and data from herring stomach analyses were used to obtain information on food and feeding habits, and to test for a possible relation between plankton abundance and commercial catches of herring.

Studies of the composition, abundance, and distribution of zooplankton communities in the Passamaquoddy area showed that copepods dominate except at a few localities where occasionally the larvae of barnacles or other groups were abundant. Volumes of plankton in all tows were usually found to be four to five

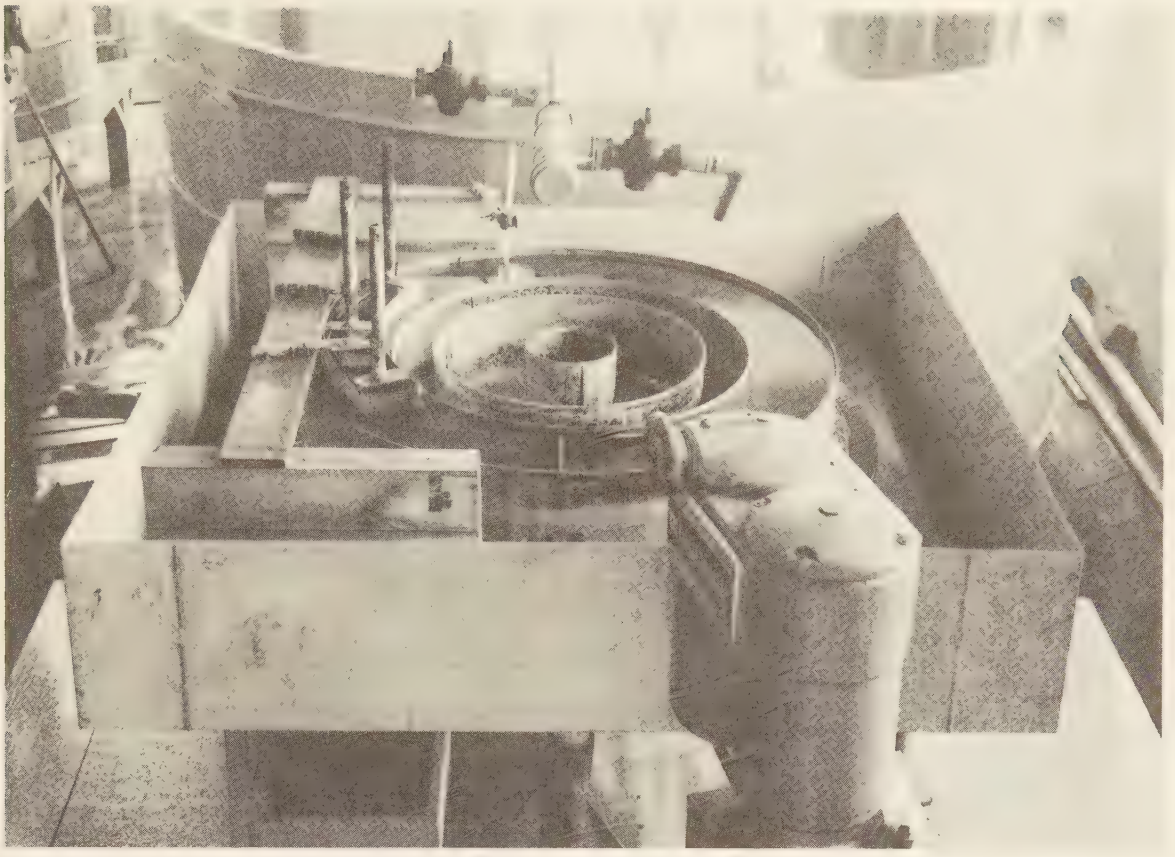

Figure 10.--Rotating tank used to measure the swimming speeds of herring.

times larger outside than inside Passamaquoddy Bay. The seasonal abundance of plankton varied greatly. The vernal crop of phytoplankton extended from late March to late June, while the largest volumes of zooplankton were taken during the summer months. Phytoplankton "bloom" ended abruptly in the summer while zooplankton populations decreased more slowly and were at their lowest ebb during the spring.

The stomachs of 1,696 herring taken in 1958 were examined for kinds and quantities of food organisms. The importance of plankton in the diet of the herring varied according to the availability of food in different localities. Copepods were the main food items, but the diet was quite diversified, and about 50 different organisms were identified. No correlation was found between standing plankton crop and feeding activity. A period of low feeding activity extended from March to August, while from September to November feeding activity was high. There was no apparent relation between plankton abundance and commercial catches of herring.

Exploratory fishing.--Exploratory fishing was carried on during 1957 and 1958 to provide additional information on the movements of herring, to supplement shore sampling program, and to locate unexploited herring populations. Electronic detection equipment and various kinds of fishing gear were used.

Exploratory fishing operations confirmed the presence of a large spawning population of herring on the northern edge of Georges Bank in the autumn and located small quantities of postlarvae in inshore areas of eastern Maine in the spring. Weekly sonic-sounder cruises during the summer months in 1957 and 1958 showed that, in general, the largest concentrations of herring in the Quoddy Region were in open waters where there are no weirs. Attempts to catch these fish with midwater trawls and gill nets were unsuccessful but large quantities were taken by commercial purse seiners. The species of fish taken in the Kennebecasis and Long Reach areas of the Saint John River were the same as those common to the Quoddy Region.

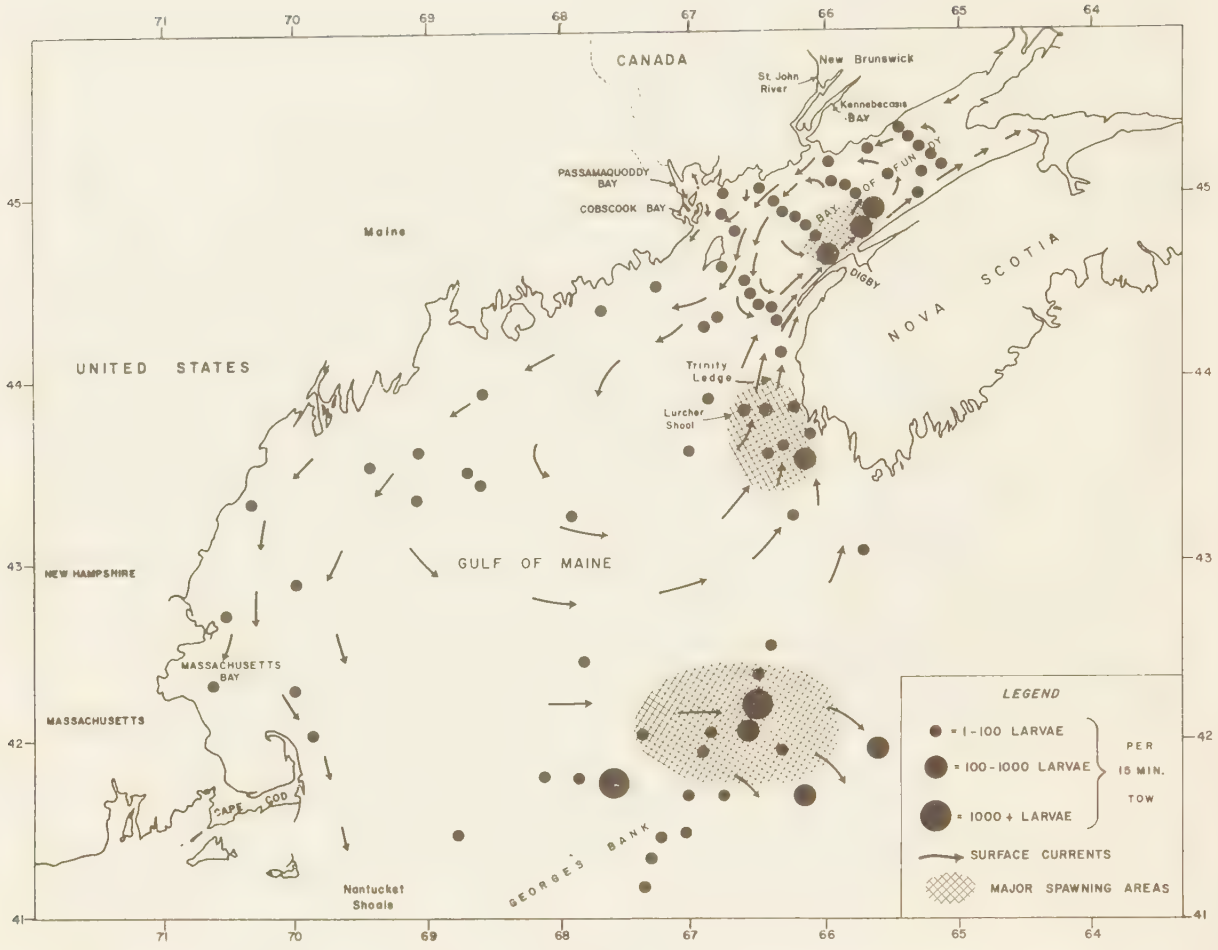

Figure 11.--Spawning areas, distribution, and abundance of herring larvae, and surface currents in the Bay of Fundy and Gulf of Maine during the autumn.

Correlation studies.--Correlation studies were undertaken because an understanding of the changes associated with present fluctuations in the herring catch might assist materially in predicting changes resulting from the dams. It was impossible, however, to establish any consistent correlation between catch and such factors as river discharge, wind speed and direction, air and sea temperatures, salinities at various depths, plankton, and cloud cover.

Other Species

Groundfish.--Commercially important species of groundfish in the Quoddy Region are pollock, haddock, cod, hake, and winter flounder. Hake and cod are scarce inside the proposed dam areas. Large catches of pollock are made in the low-pool area and small catches of haddock and winter flounder in the high-pool area. The present (1958) catch of all groundfish species in the Region is approximately 6 million pounds, of which approximately 2 million pounds (chiefly pollock) are taken inside the proposed dam areas. The haddock are fast-growing fish of the type caught off the New England States. Tagging studies show that they migrate south for the winter months and spawn outside the Region.

Mollusks.--Only two species of molluscan shellfish are harvested from the Quoddy Region in sufficient quantity to warrant consideration: soft-shell clams in the intertidal zone and sea scallops

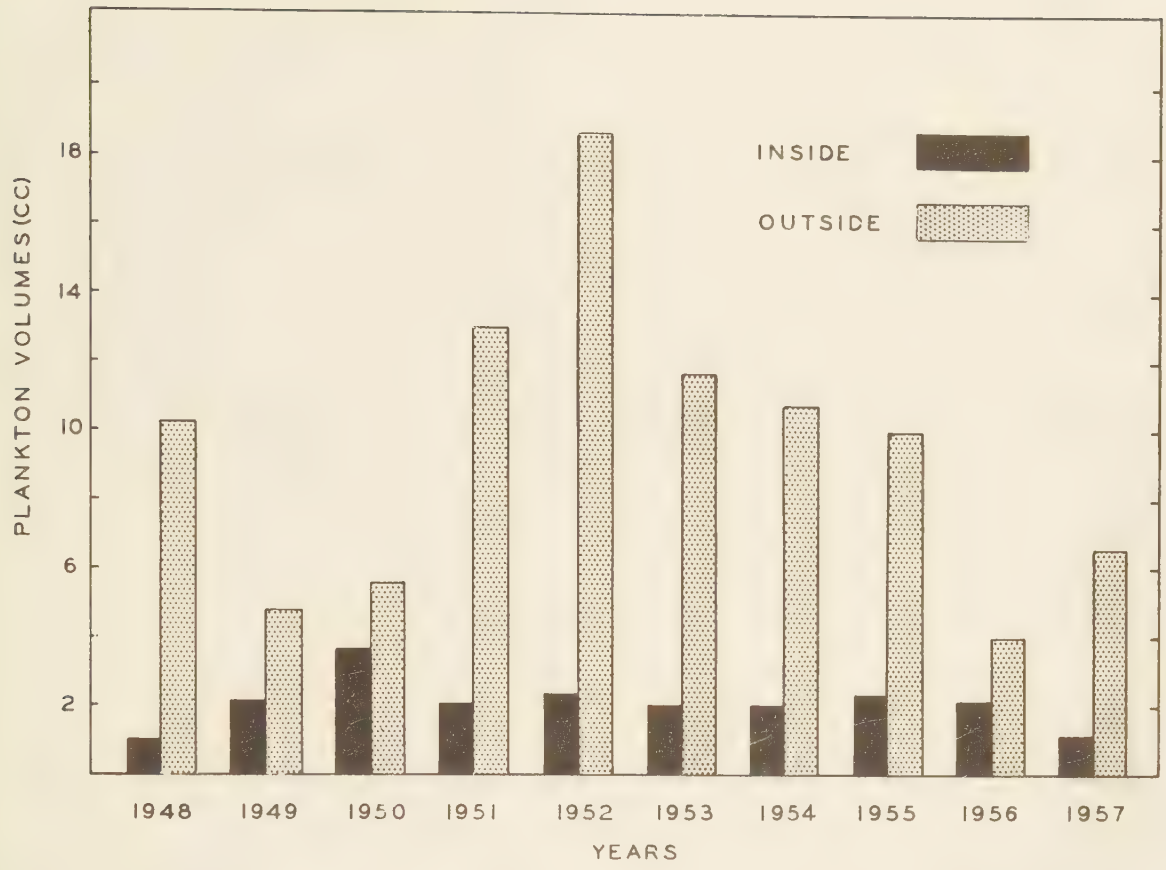

Figure 12.--Relative abundance of plankton inside and outside Passamaquoddy and Cobscook Bays. Only forms which constitute food for herring are included.

in deeper waters. In recent years the average annual landings inside the proposed dam areas have approximated 750,000 pounds of clam meats and 60,000 pounds of scallop meats. The abundance of both species has fluctuated widely and will continue to fluctuate with or without impoundment. Maintenance of scallop populations seems to depend on retention of the free-swimming larvae over their native beds until they mature and attach themselves. Evidence of shipworms, although not previously recorded from Passamaquoddy Bay, was found during this investigation in two tributary inlets--Kitty Cove and Sam Orr Pond. The species appeared to be *Teredo navalis*. Another wood borer *(Xylophaga)* is common in the offshore waters of New England and in recent years has invaded the inshore waters south and west of Mount Desert Island, Maine.

Lobsters.--From 1952 to 1958, lobster landings in the Quoddy Region averaged approximately 388,000 pounds. Of this amount, about 102,000 pounds were taken inside the proposed dam areas. Tagging has shown that adult lobsters do not move appreciably from one area to another, and hence the stocks are considered to be relatively separate and distinct.

Anadromous fishes.--Anadromous species with actual or potential economic value in the Quoddy Region include Atlantic salmon, trout, smelt, and alewives. The entire value of trout and most of the value of salmon lie in their fresh-water sport fisheries. The Dennys River is the most important salmon river and from 30 to 100 fish are angled there annually. The Digdeguash and Magaguadavic Rivers now have quite good populations of young salmon which probably contribute adult salmon to commercial catches over a wide area of the Atlantic coast. The St. Croix River has few naturally produced salmon due to obstructions and pollution.

The present sport fishery for trout is quite valuable but is based chiefly on fish which do not go to sea. Tomcod, shad, and striped bass are not fished commercially in the Quoddy Region but provide valuable fisheries in warmer, less saline estuaries. Smelt populations are probably localized and may stay within Passamaquoddy and Cobscook Bays, whereas alewives move into and out of these Bays.

Miscellaneous.--Marine worms, valued as bait for sport fishing, are harvested in small quantities in Cobscook Bay. Rockweed is a potentially valuable resource and is available in good supply. The gribble *(Limnoria),* a crustacean wood borer, is common in the Quoddy Region, and damages caused by it are significant.

ECONOMIC STUDIES

Economic surveys of the principal fisheries of Charlotte County, N. B., and of the Passamaquoddy section of the State of Maine, were made for the years 1956 and 1957. The study assessed the investment and income position of the herring and lobster fisheries, including the herring-carrier fleet, and determined the value of investment in plant and equipment and the manufacturing costs of fish-processing establishments. Groundfish and shellfish, species of commercial importance, were not covered by the economic surveys but were studied from other statistical sources. The results provide a basis for evaluating the economic impact of any change in the primary and secondary fisheries of the Quoddy Region. The primary fishery includes all activities associated with catching fish and delivering them to the processing plants; the secondary fishery includes the fish-processing activities after delivery of the fish to the plant.

Canadian fisheries

The investigation of the primary fishery was conducted on a sample basis. For the secondary fishery, a complete coverage was made of processors from Blacks Harbour to the International Boundary.

Herring weir fishery.--Like most inshore fisheries, the Canadian herring weir fishery is decentralized and dependent upon intensive application of labor. It is organized in small enterprise units, consisting typically of one weir (with a crew of about four men per weir), in which the traditional "lay" (share) system of payment to labor and capital still prevails. About 50 percent of the weir workers are hired laborers--tendermen, so-called--who have no equity in the capital of the enterprise but tend and operate weirs for a predetermined share of the season's catch. Only in a few, isolated cases do these workers receive a stipulated money wage. Thus, owners are relieved of a great deal of risk and uncertainty; the risk is further reduced by the fact that equity capital in most weir enterprises is small and spread among several owners.

Despite a basic similarity in weir construction, considerable variation in weir investment exists within and between different parts of Charlotte County. This variation is due to differences in weir sizes and in topographic and oceanographic environment. Survey data obtained for 1956 and 1957 revealed an average weir investment (including associated weir gear) of about $5,500 inside Passamaquoddy Bay and of about $6,200 outside the Bay. Total investment in weir enterprises for the entire region was placed at $1.7 million. Approximately 1,100 men are engaged in the weir fishery.

Income derived from the weir fishery is largely a function of the success of the catch. Owing to the nature of the market, prices which fishermen receive are relatively inflexible. At the same time, operating expenditures are fairly stable and subject to little influence from variations in receipts. Consequently, fluctuations in catches within the region and from year to year can engender wide variations in earnings among fishermen, and a series of unsuccessful catches can leave the weirmen in rather poor circumstances.

Data obtained on 86 weir enterprises for 1956 and 1957 provided tangible evidence of this connection. In 1956, operating incomes of these enterprises ranged from $-1,671 to $15,565; in 1957, from $-1,653 to $16,117. Average net income per enterprise was $1,385 and $2,040,

Figure 13.--Typical Canadian weirs. In the foreground, a simple weir without a parlor. In the background, a compound weir with a parlor in which herring are held alive awaiting sale.

respectively for 1956 and 1957. Average share to capital (before allowance was made for depreciation) was only $434 and $732. Despite such low and often discouraging returns, weir owners continue to maintain their investment in this operation and are generally opposed to the use of alternative methods of herring fishing.

Herring purse-seine fishery.--In contrast with the weir fishery, the Canadian herring purse-seine fishery is carried out by mobile, highly capitalized

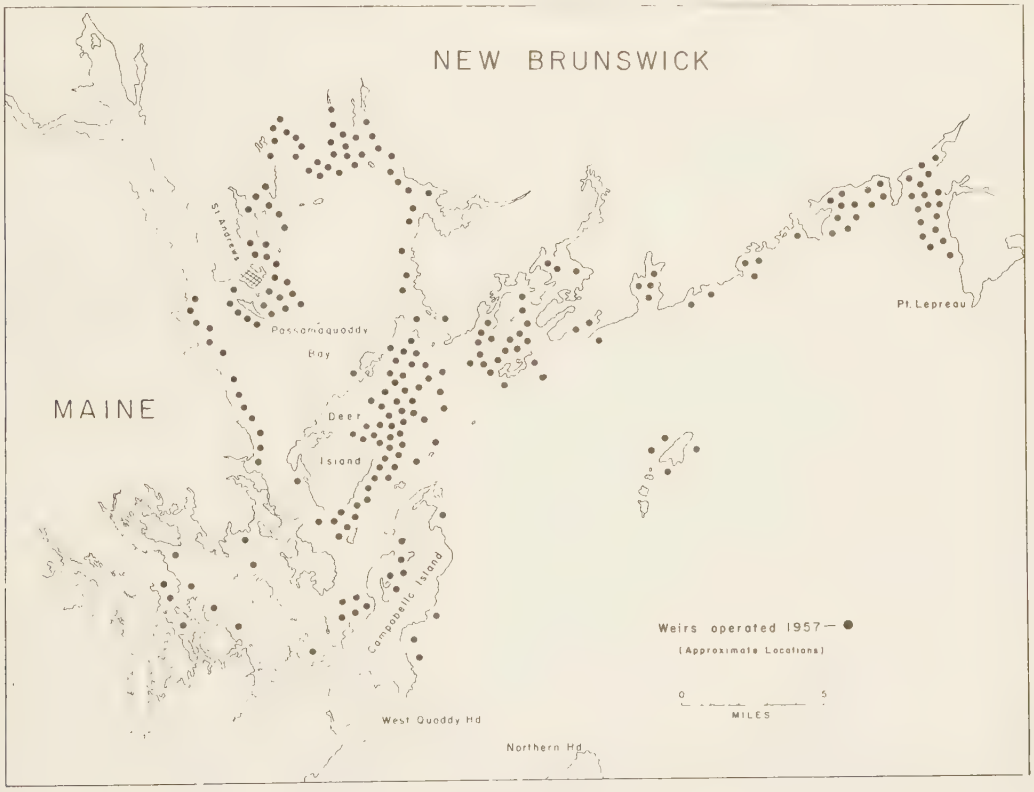

Figure 14.--Approximate locations of Canadian and United States herring weirs operated in the Quoddy Region in 1957.

fishing enterprise units. The fleet is composed of 17 vessels (with four to seven men per vessel), representing a total capital investment of about $170,000. While seiners operate under high fixed costs, their catching performance permits recovery of fairly high returns. Data on six seiners covering 1957 operations revealed an average net income per vessel of $26,445. Average crew earnings were $3,818 per man, while the net boat share averaged $4,172. There was a return of 22.4 percent on invested capital.

Notwithstanding this relatively good performance, the history of the seining fleet has been one of uneasy expansion and restricted operation. This situation has resulted from limited markets for fresh herring and local opposition to seining activity, particularly on the part of weir interests and lobster fishermen. Seiners have operated much like a fettered fleet: their movements have been restricted to certain distances from shore and from the sites of stationary fishing gear and their fishing effort has often been reduced, due to the inability of the market to absorb the catch. There is hope, however, that new channels of herring utilization will alter the existing supply-demand relationship and, thereby, reduce local opposition to the application of efficient capital in the herring fishing industry.

Herring carrier fleet.--This fleet is a necessary adjunct to the weir and purse-seining fisheries. Vessels vary greatly in size--from about 40 feet to 65 feet--and carry a crew of one to three men. In 1957, there were 57 independently operated vessels engaged in the carrying trade, representing an average capital investment of $6,496 (based on survey data covering 46 vessels). Values ranged from $350 to $21,650. Total net income from carrying operations--derived mainly from the herring trade--showed little change during the 2-year study. The average income per vessel was $4,072 in 1956 and $4,115 in 1957. This uniformity was due to the supply-demand relation for the commodity transported and to the constancy of both receipts and expenditures in the region as a whole.

Lobster fishery.--In the Quoddy Region this fishery is small compared with that in some areas of the Maritime Provinces. During the 10-year period ending in 1957, the value of lobster landings averaged about $0.5 million per year. Typical lobster enterprises consist of one or two men, with investments in a small boat, in about 150 lobster traps, and in a modest stock of shore equipment. A small capital outlay in gear and equipment for use in other fisheries usually accompanies the "lobstering assets." Total investment of lobster enterprises in Charlotte County is estimated at $659,000 representing an average of about $1,985 per enterprise. Investment varies among the several subdivisions of the area. In Grand Manan, in particular, lobster enterprises use more gear and are generally more heavily capitalized; net returns per man are higher. Operating expenditures in the lobster fishery are fairly inflexible and relatively independent of results of the catch. The net income, however, is subject to considerable variations from year to year in response to supply and price conditions. In 1957, the average net income of 22 lobster enterprises was $811.

Groundfish fishery.--In Charlotte County this fishery is pursued by approximately 350 men, fishing mainly on inshore grounds, using small motor boats and limited capital equipment. The value of their landings from 1948 to 1957 averaged about $270,000 annually. Since 1950, a trend toward modernization and expansion has developed. Largely through government assistance, mechanized vessels (chiefly draggers) have been introduced and have had appreciable success in improving fish landings and incomes of fishermen. A modern large-scale filletting and freezing plant was established in the area in 1957 and has greatly increased the local demand for groundfish.

Mollusk fisheries.--Clams, mussels, and scallops support the principal Canadian fisheries for mollusks in the area. There are an estimated 300 men engaged in these fisheries. Most of these men participate in other fishing activities. The income derived from shellfish landings averaged about $225,000 annually from 1948 to 1957. Clams constituted about three-quarters of the total value. Capital equipment associated with the shellfish fisheries in Charlotte County is negligible. Largely for this reason, the fisherman's expenditures are small; consequently, receipts from the sale of mollusks approximate a net reward for labor.

Fish-processing.--In Charlotte County the industry is dominated by sardine and lobster plants. A number of plants process other species on a small scale, principally groundfish and clams.

Investment in plant and equipment of all processors in the area was calculated for 1957 to exceed $7.0 million (based on replacement values). The direct influence of this industry upon the economy of the area can be measured, at least in part, in terms of the employment which it generates. This employment is largely seasonal in nature, reaching its peak during the summer months. In 1957, for example, the number of persons employed ranged from about 1,400 in July to 450 in December.

United States fisheries

The survey of the primary fisheries in the Quoddy Region of the State of Maine covered investments, operating costs, and net returns to fishermen for 1956 and 1957. Data on investments, operating costs, and gross stock of herring carriers were also collected. The survey of the secondary fisheries obtained, whenever possible, similar data from fish processors, such as smokers, sardine packers, fishmeal and oil producers, and pet-food canners. The primary fishery is concerned principally with herring. Other commercially important species are clams and scallops. Lobsters, groundfish, alewives, and smelts are of minor importance. Comparatively small catches of species other than herring and scallops involve limited gear investment, negligible operating costs, and small profits.

Herring weir fishery.--The United States fishery in the Quoddy Region is small compared with the Canadian fishery. Two types of weirs are used--the "beach

Figure 15.--A typical United States stop seine. In the background, note the pocket for removing the "sardine" catch.

Figure 16.--United States herring carriers.

weir'' and the ''patent weir.'' The beach weir requires more material and labor to construct, while the patent weir has fewer and larger stakes with netting, which can also be used in stop-seine operations. All beach weirs are owner-operated, with the season's catch and expenses shared with one or two tendermen. Patent weirs, in most cases, are operated in conjunction with stop-seining activities and usually are not in operation unless herring are seen in the vicinity. They can be put into operation in 1 to 3 days, while the beach weir requires several weeks, both ashore and afloat.

There were 19 weir enterprises that operated 24 weirs inside the proposed impoundment area in 1957. Their total value was more than $133,000. Approximately 40 men were engaged in the weir fishery. Data obtained for 1956 and 1957 revealed an average weir investment of about $5,555. The average gross income per weir was $1,478 and the net cash return was $829. In 1956, the net income, before allowance for depreciation, ranged from $-660 to $7,059; in 1957, from $194 to $5,006. Income derived from the weir fishery depends on both catch and selling price, which vary according to availability of the fish.

Herring stop-seine fishery.--In the Quoddy Region, seven United States vessels (with two to five men per vessel) participate in this fishery. Total capital investment is about $107,000 with an average value of $15,000 per vessel. In 1956, the gross income per seiner, before depreciation, ranged from $1,035 to $12,502. On some vessels, a large percentage of the fishing gear is financed by sardine-canning companies to insure preference in obtaining their catches.

Herring carrier fleet.--In 1957, 15 United States herring carriers operated in the Quoddy Region. Their total value was more than $290,000. Carrier values ranged from $6,200 to $38,000. Nearly all have fish pumps, radar, and other electronic equipment. The carriers are owned and operated by eight sardine plants, and their owners consider them as part of the secondary industry. Profits for the herring-carrier fleet cannot readily be computed, but their total expenses in 1957 ranged from $924 to $8,558.

Groundfish fishery.--Annual United States groundfish (cod, haddock, and pollock) landings taken by hand line, trawl line, and lift net from the low-pool area average 400,000 pounds, worth about $6,000. Investments in equipment are generally small (about $100 per lift-net unit). The number of persons engaged in

the fishery each year fluctuates widely from about 6 to more than 50.

Lobster fishery.--The low level of United States lobster landings--less than 1,000 pounds valued at less than $400--makes it a subsistence fishery only carried on by some 15 to 20 part-time fishermen. Lobster traps have a total value not exceeding $400.

Mollusk fishery.--Landings of mollusks (soft clams, scallops, and periwinkles) have averaged less than 300,000 pounds worth about $80,000 each year for the past decade. Clam landings have declined 100,000 pounds since 1957 and scallop production in 1958 dropped to less than 4,000 pounds, the lowest level since 1948. An average of 108 diggers were engaged in the clam fishery with investments in equipment not exceeding $3,000. Investments in locally owned scalloping equipment amounted to less than $5,000.

Fisheries for anadromous species.--Commercial landings of alewives and smelts in the United States averaged 280,000 pounds worth between $5,000 and $6,000 annually during the past decade. Investments in equipment do not exceed $1,000; not more than a $\frac{1}{2}$-dozen fishermen are engaged in the alewife fishery and less than 50 in the smelt fishery.

Miscellaneous.--In 1958, sand worms were taken commercially for the first time in the Passamaquoddy area. Preliminary surveys indicate concentrations of probable commercial importance in Lubec, Pembroke, and Eastport.

Fish processing.--The survey of the secondary fisheries covered the herring-processing industry of the Quoddy Region for 1957. There were 11 sardine and 2 pet-food canneries, 6 smoke houses, and 9 fishmeal and pearl-essence plants. Total value of herring products was more than $11,000,000. Pet-food plants accounted for 49 percent of this value, compared with 37 percent for the "sardine" plants. Although the operation of "sardine" plants is seasonal in nature, employment in them accounts for about 80 percent of the total number (1,671) employed in the fish-processing industry. Reduction and pet-food plants employed more than 11 percent.

Figure 17.--A United States sardine cannery.

Predictions and Conclusions

The results of these investigations provide the basis for predicting effects which the proposed tidal power structures might have on the fisheries of the area. Consideration is given first to anticipated changes in oceanographic conditions if the dams are constructed. Changes in environment will then affect distribution, behavior, and abundance of fish stocks, and these in turn will affect the economic status of the fisheries in the area.

OCEANOGRAPHIC EFFECTS OF IMPOUNDMENT

Tides, circulation, and distribution of properties have been described in general, but only a qualitative evaluation of their relation to controlling factors has been possible. Without a quantitative relationship, precise predictions as to what will happen under a new set of controlling factors cannot be made. It should be borne in mind that the predictions given here can place only approximate limits on the changes anticipated.

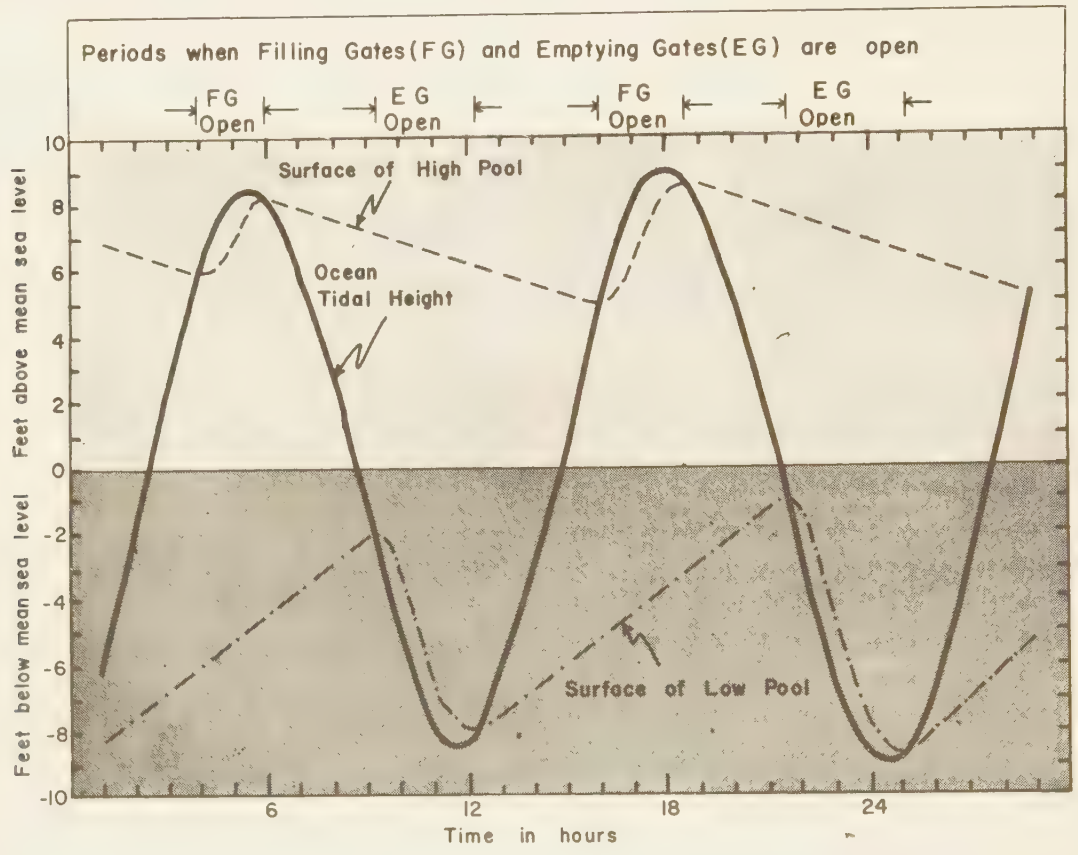

Figure 18.--Daily cycle of power-project operations showing the variation in water level for the high pool, low pool, and outside areas. Periods when filling and emptying gates are open are also shown.

It was instructive to consider pertinent aspects of other areas, e.g., Kennebecasis Bay, Oak Bay, Northumberland Strait, British Columbia inlets, in which certain oceanographic factors bear a degree of similarity to the anticipated conditions in the Quoddy Region. By making simplified assumptions about the nature of the mixing process expected under the proposed conditions for the Quoddy Region, distribution and accumulation of fresh water in the St. Croix and the Magaguadavic estuaries were computed. Flushing times of the high and low pools were estimated.

The following gross effects and tendencies can be expected in the high and low pools and in the outside area. Engineering details pertinent to the oceanographic predictions were supplied by the International Passamaquoddy Engineering Board.

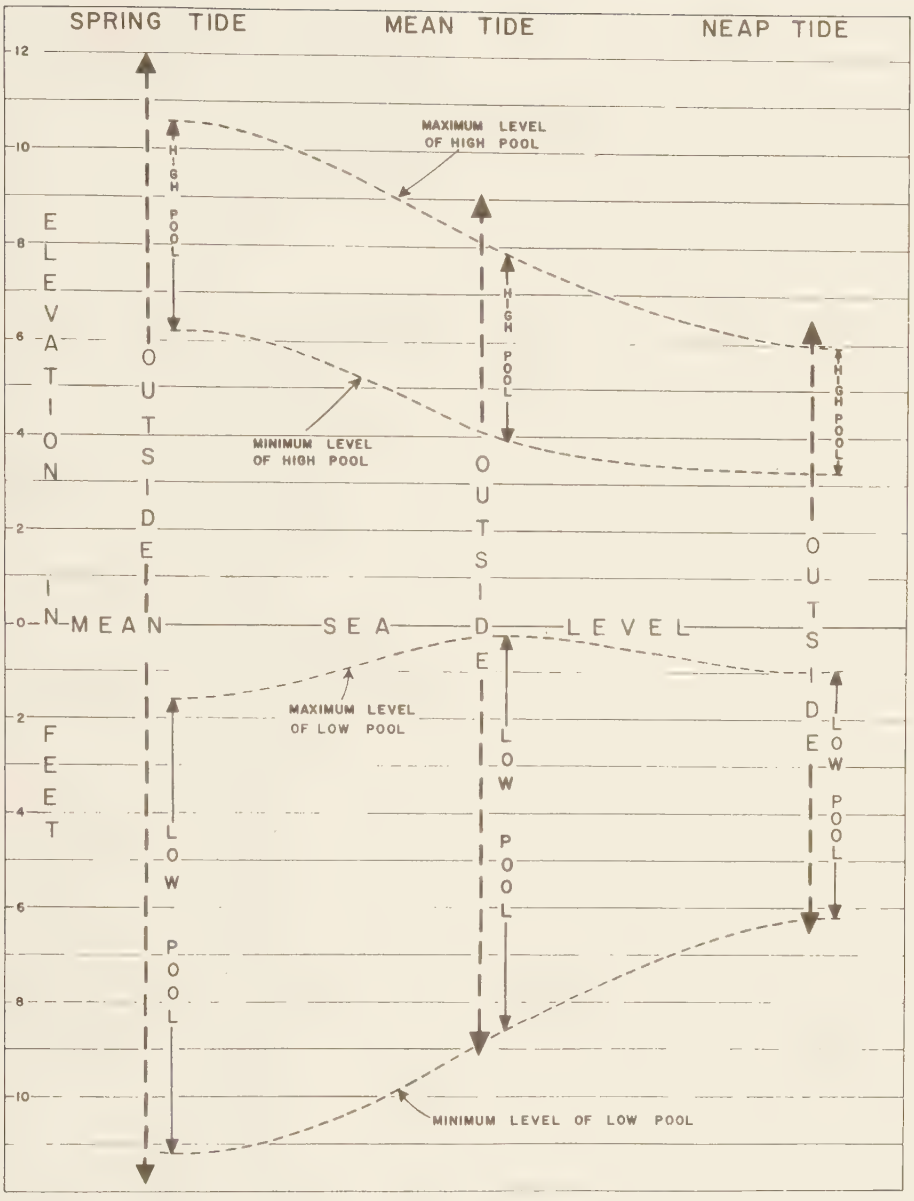

Figure 19.--Schematic illustration of elevations and ranges of water levels in the high pool, low pool, and outside areas for spring, mean, and neap tides.

Water levels

The mean level of the high pool will be raised about 6 feet with a tidal range averaging 4 feet. Minimum and maximum ranges will be $2\frac{1}{2}$ and $4\frac{1}{2}$ feet. Minimum elevation, which will occur during neap tides, and maximum elevation, which will occur during spring tides, will be 3 feet and 11 feet above mean sea level.

The mean level of the low pool will be lowered 5 feet with a "tidal" range averaging 8 feet. Minimum and maximum ranges will be $5\frac{1}{2}$ and $9\frac{1}{2}$ feet respectively. Maximum elevation, which will occur during mean tides, and minimum elevation, which will occur during spring tides, will be zero and -11 feet respectively relative to mean sea level.

Due to configuration, the tidal range of the Bay of Fundy may increase approximately 1 percent. The increase in maximum range will occur at the head of the Bay of Fundy and should be less than 1 foot.

Currents

For about $9\frac{1}{2}$ hours in a tidal cycle of $12\frac{1}{2}$ hours, the filling gates will be closed. Water will leave the high pool continuously through the turbines. While the filling gates are closed, the only motion will be towards Western Passage and will be contained mostly in the upper 45 feet. Mean velocities of the upper layer are expected to be about one-fifth of the present values. When the gates are open, velocities should be similar in most areas but slightly lower than at present. A residual counterclockwise circulation in the Bay will likely be more pronounced.

When the emptying gates are open, velocities in the low pool will be similar to present values at half-ebb. While the emptying gates are closed, the flow will spread in both directions from the low-pool side of the powerhouse. During this period, the velocities in Cobscook Bay should be less than one-third the present value west of the powerhouse and approximately one-fifth the present value between the powerhouse and the emptying gates. The vertical-longitudinal circulation in Cobscook Bay west of the powerhouse will be an inward movement of the deeper water and a seaward movement of the surface layer.

In the outside area there is little indication that significant changes in residual flow will extend much beyond the Head Harbour-Bliss Island Region. Tidal streams should be reduced in the approaches to the passages and increased in other areas of the Quoddy Region. The direction of tidal streams will be altered only slightly, and changes in speed are not expected to exceed 20 percent of their present value. For about 6 hours in $12\frac{1}{2}$, speeds inside the Head Harbour-Bliss Island line will be very small. When the filling gates are open, flow in the Bliss Island region should be similar to that at present, but reduced slightly in the Head Harbour region and increased in the channel between Indian Island and Deer Island. Most of the water entering the Western filling gates will be water that has drained from the low pool. Inflow through the Letite filling gates will be mostly "new" water from outside the dams. Residual flow, which will be more marked than at present, will be inward toward Letite Passage and outward from Head Harbour Passage. Wind speed and direction should play an important role in controlling the amount of water recirculated through the Letite gates.

Water temperature

Reduced velocities in the high pool will result in decreased vertical mixing, permitting increased stratification, and hence greater seasonal variations in the temperature of the surface waters. These variations will be minimum near the Letite filling gates (altered only slightly from present conditions) and maximum along the north shore of Passamaquoddy Bay and in the St. Croix estuary. Maximum summer temperatures at the surface are likely to be in the vicinity of 68° F. The surface layer will probably be less than 10 feet in depth most of the time, but on occasion may deepen to 30 to 50 feet. Below this depth, temperatures will be altered only slightly, with the expected range falling within 32° F. and 56° F. Ice cover is expected to occur over part of the Bay in winter.

Stratification will not be as marked in the low pool as in Passamaquoddy Bay, except in the upper reaches. Summer maximum at the surface in the inner part of the Bay may reach 68° F. The outer area is unlikely to exceed 60° F. Summer temperatures of the bottom water may increase by 4° to 5°, while winter temperatures will be lowered only slightly. Ice cover is likely to occur in the inner part of the Bay during the winter.

Little change is expected in the outside area except contiguous to the emptying and filling gates and mostly inside the Head Harbour-Bliss Island line, where a somewhat greater seasonal variation is expected.

Salinity

Mean surface salinity in the high pool will be lowered. Bottom salinities should be altered only slightly. During freshets, surface salinity may drop below 20 parts per thousand (normal sea water in the Bay of Fundy is approximately 33 parts per thousand). At other times of the year, surface salinity should be between 20 and 30 parts per thousand, except in the St. Croix estuary above St. Andrews and in

the north part of Passamaquoddy Bay. Maximum surface salinity will occur just inside Letite filling gates and will exceed 30 parts per thousand. Fresh water is not likely to penetrate below 30 to 50 feet, and the bulk of it will be confined to the upper 5 to 15 feet. Flushing time is expected to be increased markedly.

All saline water will enter the low pool through the turbines and will carry with it the total fresh water discharged into Passamaquoddy Bay. Mean salinity should therefore be lowered. Decreases should not exceed 3 to 4 parts per thousand (i.e., salinity not less than 28 parts per thousand) except during peak runoff. Bottom salinities should not drop below 28 parts per thousand. Stratification should not be very marked except in the upper reaches of Cobscook Bay. West of Leighton Neck, however, a thin layer, probably not more than 3 feet thick, may be quite brackish and at times drop below 20 parts per thousand. Flushing time is expected to be increased substantially.

In outside areas, significant changes are expected only adjacent to the emptying gates and inside the Head Harbour-Bliss Island line. Reduction in salinity is unlikely to exceed a few parts per thousand.

Oxygen content

At present, due to vigorous tidal mixing, water in the Quoddy Region is nearly saturated with oxygen. Under proposed conditions, mixing will be decreased inside the impoundment and oxygen concentrations of water in the deep basins of Passamaquoddy and Cobscook Bays may be reduced. Rates of water renewal, and hence rates of oxygen supply to the deep water within the basins, will be minimal during periods of maximum fresh-water discharge into the Quoddy Region. However, oxygen concentrations are unlikely to fall below 50 percent saturation.

BIOLOGICAL EFFECTS OF IMPOUNDMENT

In the biological study, particular attention was given to herring, the most important commercial species in the Quoddy Region. This study included catch statistics, identification and origin of populations, food and feeding habits, behavior, and migrations. Catch statistics and published information on other species were evaluated. Anticipated changes in oceanographic conditions were considered in predicting changes that may take place in all commercially important species as a result of the proposed dams.

Herring

Herring stocks in the Quoddy Region are produced outside, probably in southwest Nova Scotia waters. Since environmental changes are anticipated only inside the bays and immediately outside the proposed dams, it is extremely unlikely that the abundance of herring will be affected. Most of the plankton that makes up the food of herring is also produced outside the Quoddy Region, and no major change in its abundance and distribution is anticipated.

Tagging experiments indicate that herring move freely in and out of Passamaquoddy and Cobscook Bays during the fishing season with some tendency to concentrate at the head of Passamaquoddy Bay. It is not expected that the installation and operation of the proposed dams will affect the movement of herring to the Quoddy Region, nor should the distribution of fish, except in the bays and immediately outside the dams, be affected. It has been predicted that significant changes are unlikely in oceanographic conditions outside the Quoddy Region beyond the Head Harbour-Bliss Island line. Herring should therefore arrive outside the passages as before. It has been concluded from behavior studies that herring will swim against a current only when they can see fixed objects such as the bottom. Most of the year, herring are in the upper-water layers and, hence, probably will be transported passively in the current. For most of the period when they are open, the current through the filling gates and for some distance outside will exceed 5 feet per second. This velocity exceeds the maximum swimming speed of herring and the fish will be carried into the high pool. Since the filling gates are open only for about 6 hours each day, movements of fish into Passamaquoddy Bay will be delayed. This short period during which the gates are open will affect the rate at which herring accumulate inside Passamaquoddy Bay. However, recaptures from tagging

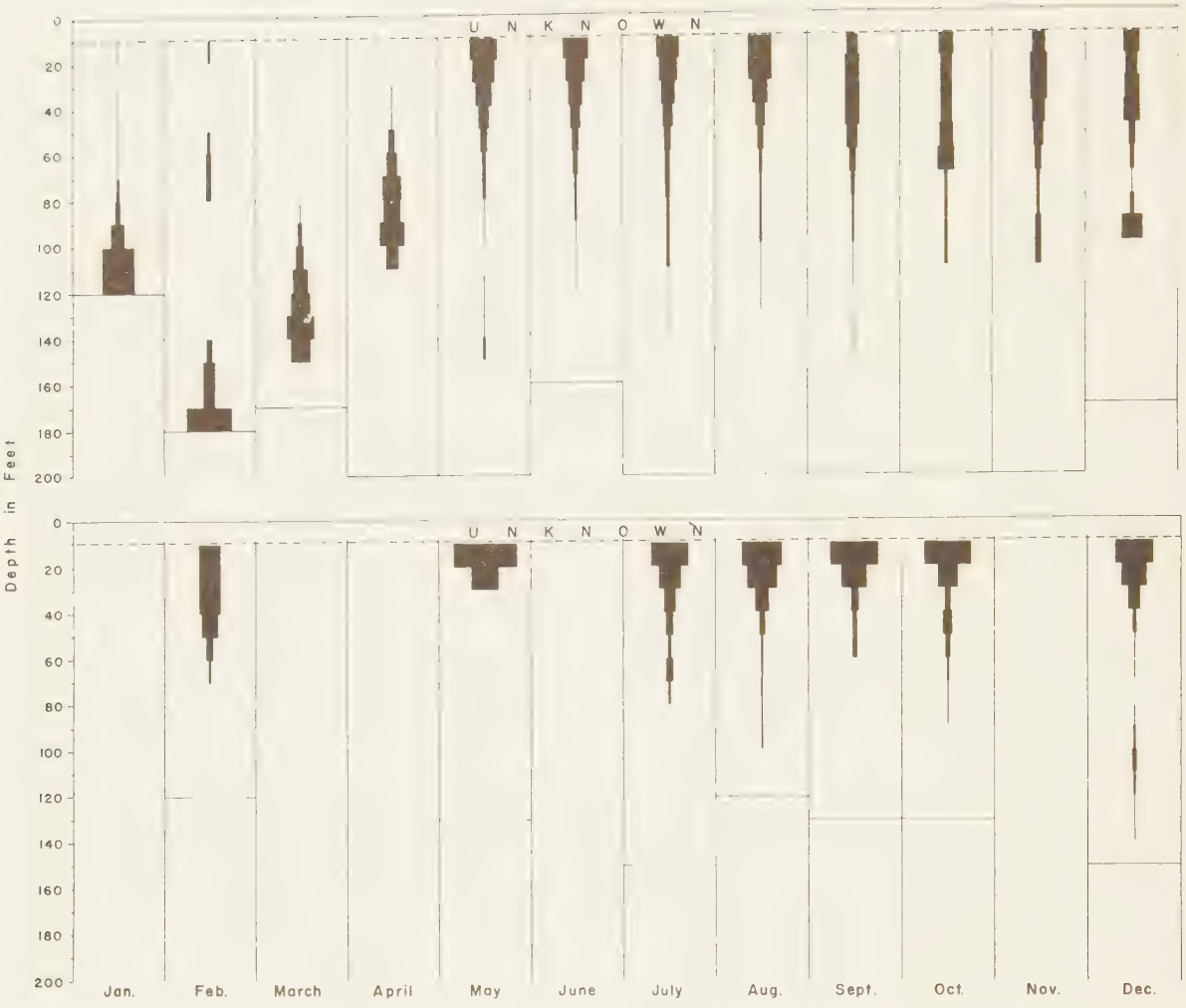

Figure 20.--Depth distribution of herring schools in Passamaquoddy Bay as determined by sonic-sounder recordings (upper) day, (lower) night.

and results of echo-sounder surveys suggest that fishing mortality is low, hence there should be no reduction in the abundance of herring inside the Bay.

Herring will be unable to enter Cobscook Bay directly from the outside except in insignificant numbers through the navigation locks and filling gates. Entry into Cobscook Bay and exit from Passamaquoddy Bay will be possible only through the turbines. As a result, movement into Cobscook Bay and away from both Bays will be altered both in time and direction. Most of the water entering the Western filling gates will have been discharged from the low pool, whereas inflow through the Letite filling gates will be mostly "new" water from outside the dams. Therefore, recruitment of herring to Passamaquoddy Bay is expected to be mainly through the Letite filling gates.

The predicted salinities of 20 to 30 parts per thousand in the upper (10 to 15 feet) water layers of the high pool during normal summer conditions are well within limits that herring can tolerate. If temperatures in this layer reach or exceed the predicted value of 68° F. and especially if they rise above 70° F., herring mortality might be high. Temperatures of this order may occur only in isolated or sheltered coves, and any mortality due to high temperature and low salinity should be limited in time and extent. It is possible that herring will avoid

warmer, less saline water. In the low pool, herring should be able to survive the altered salinities and temperatures except for localized mortality if temperatures exceed 68° F. Predicted pressures and rates of pressure change between turbine intakes and exits are within limits that herring have been shown to withstand. In passing through the turbines, some fish will undoubtedly come in contact with the sides of the draft tubes and with the turbine blades. This contact may cause some abrasion with a resultant mortality, but the effect is expected to be insignificant.

Most of the herring are taken in weirs built close to shore. Analysis of weir catches shows no significant relation between average catches inside Passamaquoddy and Cobscook Bays and catches in outside areas for the same year. Weirs inside the bays are more efficient and catch about twice as many herring per weir as those outside the bays. This suggests that the bays act as a natural fish trap and tend to hold herring in a restricted area.

The only significant change expected is a time lag in the entry of herring into the bays resulting from closure of the filling gates for about 19 hours in every 25. However, the most significant point established from the results of investigations is that year-to-year variations both in individual weir catches and in total catches in the various statistical districts of the Quoddy Region are far greater now than any that can be forecast as resulting from the installation of dams.

Groundfish

No measurable change in groundfish landings is anticipated for the Quoddy Region, but there will be a change in the species composition of the fraction of the catch taken inside the dams. Winter flounders should increase in numbers since anticipated conditions will more closely resemble those to the south where there are important winter flounder fisheries. A larger commercial and sport fishery for winter flounder is visualized. The proposed structures will probably eliminate the haddock fishery inside the bays, but no effect is expected outside. Impoundment will deny fish direct access to the low pool and therefore sharply reduce the pollock fishery there.

Mollusks

It may be assumed that clam production will vary with the size of the intertidal zone. This zone will change in size and position if dams are installed. In the high pool, which yields roughly half the total clam production in the Quoddy Region, the present beds will be permanently submerged. Consequently, clam production will decrease drastically with impoundment. There will be no substantial clam production in the high pool until new beds are established at new intertidal levels and until the clams there have grown to marketable size. This should take from 6 to 10 years and even then production may be only 5 percent of its present volume. In the low pool, production should drop to 50 percent of the present small volume, but after 6 to 10 years it should rise to the present volume. In the outside area no changes are anticipated.

Impoundment is expected to increase scallop landings substantially in the Quoddy Region. In the high pool, flushing times may be doubled and hence conditions for retention of the pelagic larvae improved. In the low pool, improved conditions for feeding and survival should increase production slightly. In the outside areas there are likely to be no changes.

Turbidity and water temperature are important factors regulating shipworm distribution. The threshold temperature for spawning in *Teredo navalis* is 61° F. Because of the expected increase in water temperature in summer, a rapid spread of shipworms to all parts of both pools may be expected. The outside area will not be affected appreciably.

Lobsters

It is anticipated that only the stocks of lobsters inside the dams will be affected. The present fishery is carried out almost exclusively in Passamaquoddy Bay. If the bay becomes ice covered, the present winter fishery would be impossible but lobsters could be harvested equally well in another season. Predicted increases in surface temperatures during the

summer should favor growth and survival of free-swimming larvae. Decreased water exchange between Passamaquoddy Bay and the Bay of Fundy should favor retention and settlement of larvae within Passamaquoddy Bay. Consequently, there may be a modest increase in the lobster catch.

Anadromous fishes

Anadromous fishes that have present or potential value in the Quoddy Region include Atlantic salmon, smelt, alewife, shad, tomcod, and sea-run trout. Of these, Atlantic salmon and alewives have the greatest potential value but their status after impoundment will depend upon the efficiency and adequacy of fish-passage facilities. With stream improvements, particularly in the St. Croix River, the total annual run of Atlantic salmon into the rivers of the Quoddy Region might be increased. Adequate management should increase alewife production. Warming of sea water and reduction in tidal amplitude may favor a sport fishery for trout. The smelt, shad, and tomcod populations should increase under the new conditions. Striped bass thrive in areas where summer waters are warm and of reduced salinity, but increases in their abundance within the impoundment cannot be predicted with any certainty.

Other species

Reduction in accessible beach areas may result in a decrease in the present small fishery for marine worms in both high and low pools. Supplies of rockweed may be reduced somewhat in the low pool, but no change is forecast for the high pool or outside. Damages caused by the gribble *(Limnoria)* may become more serious.

ECONOMIC EFFECTS OF IMPOUNDMENT

Results of oceanographic and biological studies indicate that the installation of dams will not affect the abundance of herring in the Quoddy Region substantially. Consequently, operation of herring processors and of men engaged in purse seining and the herring-carrying trade will not be disturbed. However, a number of weir fishermen will be affected; some will have to relocate a few weirs situated on or near the site of the proposed dams; others, more numerous, will have to re-position weirs or alter construction to suit the new oceanographic environment. The average cost of weir operation will likely rise. At the same time, a number of weirs may gain in efficiency. Groundfish and clam fisheries inside the proposed dams are expected to be substantially reduced. There will be a drastic reduction of the clam fishery in the high pool. Other species now taken commercially inside the proposed dams (lobsters, flounders, scallops) are expected to remain relatively unchanged in abundance, with the possibility of slight improvement.

The primary fishing industry

Direct damages attributable to the proposed power project are concerned chiefly with the herring fishery. Six weirs near the dams will be destroyed by the proposed project. The replacement value of weirs, including all associated gear, inside the proposed dams averages $5,500. Assuming that weir values in the vicinity of the dams do not differ from the area average, the replacement value to be considered amounts to $33,000.

Indirect damages as a result of changes in environmental conditions brought about by the construction of dams must be given due weight in an assessment of the economic effects on the weir fishery. Four factors deserve examination: water levels, wood borers, ice cover, and tidal scour.

On the basis of predicted oceanographic changes in the high pool, weirs in this area may not be operated at their present locations unless they are modified and altered in size to fish approximately 10 additional feet of water. In particular, weir stakes and nets will need to be larger to suit the new water levels. The average value of Canadian-owned weirs, including seines, in the area is about $4,600, and the cost of weir construction can be expected to rise by approximately $1,000 after the dams are installed. The average cost of annual maintenance and repair might also increase by about $100 per weir. In the United States section of the high pool, the average value of weirs is about $4,000, and the

additional cost of construction can be expected to rise by about $1,200 per weir. The increased cost of annual maintenance and repair would be about $120 per weir.

There were 82 weirs in operation in the high pool in 1957--69 in Canada and 13 in the United States. Eleven additional Canadian weir sites were licensed but not operated that year. On the basis of these weir numbers, the initial increase in weir construction cost in this area could be expected to range from $84,600 to $95,600--$69,000 to $80,000 for Canadian weirs and $15,600 for United States weirs. The increase in total annual operating costs could range from $8,500 to $9,600--$6,900 to $8,000 for Canadian weirs and $1,600 for United States weirs.

Admittedly, some weir owners would have the alternative of relocating their weirs closer to shore or at sites farther distant. In a number of instances this might not be feasible, however, owing to the topography of the immediate environment or the unavailability of suitable sites elsewhere. In any event, it should be recognized that a certain element of disruption and, indeed, of cost, either for material or for labor, would be experienced by the majority of weir owners in the area designated as the high pool.

It is not expected that weir fishermen in the low pool would be seriously affected by the proposed project. Predicted oceanographic changes indicate, in a general way, the reverse of the water-level conditions forecast for the high pool. Weirs, therefore, could be fished at their present sites, although fishing in approximately 5 feet less water. In this event, the size of weir gear could be reduced to adjust to the new water levels. This would decrease construction and operating costs, although it might also result in a reduction of weir efficiency.

An alternative to the fishermen of the low-pool area would be to relocate their weirs, if suitable sites were to be found, in an attempt to employ existing gear to maximum potential efficiency. Such a course would entail additional costs, principally labor, in the first year of construction, but should not be significant.

On the basis of predicted changes in water temperatures following the construction of the dams, it is anticipated that the activity of wood borers will increase. While it is impossible to measure the extent of damage likely to result from this source, it should be recognized that the durability of wooden structures within the impoundment will be diminished. Thus, the life of untreated wood structures will be reduced, which will add to annual operating costs.

The temperature changes forecast lead to the conclusion that the shoreward fringes of Passamaquoddy and Cobscook Bays (except at and near the dams) will have an ice cover during the winter months after the dams are installed. In this event, weir fishermen will be faced with two alternatives: either to dismantle all structural weir material before the onset of winter for rebuilding in the spring, or to leave the structures to the hazards of winter and replace them each spring if necessary. Whatever course is followed will add to existing weir operating cost.

The construction of the dams will result in some reduction of tidal currents and wave actions, both of which now cause some damage to weirs. To some extent, this will reduce the increased costs arising from other environmental changes.

The interaction of the changes described is likely to result in an appreciable increase in average weir expenditures inside the dams. Considering the nature of the prevailing weir fishery--high, relatively inflexible costs, with correspondingly low returns--it is conceivable that weir owners will not continue to maintain their investment in weirs in the area. Should this happen, a capital investment of nearly $500,000 could eventually be displaced. A shift to alternative methods of fishing could be expected to maintain the fishery, at least at its present level.

Increased temperatures and reduced water exchange could favor the growth, survival, and retention of lobster larvae inside the dams. This might result in a modest increase in the commercial production of lobsters. Since quantitative estimates of the potential gain are not available, it is impossible to estimate

the increase in income which might accrue to the fishing community from this source.

No measurable change in groundfish abundance is predicted for the Quoddy Region after the dams are built, although the species composition of the portion of the catch taken inside the dams will change. The overall effect on Canadian fishermen is expected to be negligible. However, United States fishermen will be forced to abandon the small lift-net pollock fishery in Eastport and Lubec, with a resultant loss of approximately $3,000 annually.

With present methods of fishing, clams may not be accessible to Canadian fishermen in the high pool for a period of 6 to 10 years; thereafter, the fishery should be developed at about 5 percent of its present size. In the United States section of this area, clam landings are expected to be reduced by 50 percent immediately and remain so for 10 years. The loss to the fishermen of both countries would be about $90,900 annually for 10 years ($86,000 for Canada and $4,900 for the United States). In the low pool, clam landings will decline 20 percent in Cobscook Bay and 50 percent in the Friar Roads area, and remain at these levels for a maximum period of 10 years. The fishery should be re-established at its original or slightly higher level thereafter. The total loss to fishermen would be about $13,000 annually for 10 years ($500 for Canada and $12,500 for the United States).

The reduction in water exchange due to the dams is expected to create a more favorable environment for scallop production. Substantial increases are predicted for the high pool, resulting in an annual increase of $12,000 to fishermen ($11,500 for Canada and $500 for the United States). In the low pool, a small gain of about $1,900 annually is estimated for United States fishermen.

At present, anadromous species are of little commercial significance in the Passamaquoddy Region. After the installation of dams, conditions may well be improved for species such as salmon, smelts, striped bass, shad, and alewives. To what extent the variety and abundance of anadromous species will improve is unknown, but it could be substantial if the needed improvements are made in the St. Croix River. Conceivably, the benefits could accrue to sport fishermen rather than to those who fish for commercial gain. However, as far as the economy of the Region is concerned, the income-generating features of an improved sport fishery could, in the long run, be quite beneficial. In an effort to preserve and help improve the sport fishery, principally salmon, the construction of fishways at the power dams is contemplated. The cost of this project, as estimated by fishery engineers, is expected to be in the neighborhood of $3.0 million.

The secondary fishing industry

It is believed that the proposed project would have immediate impact on the operations of lobster- and clam-processing plants in the Quoddy Region. Two sardine-processing plants will require relocation (Sunset Packing Co., West Pembroke, Maine, and the North Lubec Manufacturing Co., North Lubec, Maine).

Because of changes in water temperatures and salinity, the relocation of two lobster pounds and the refrigeration of sea water or an extension of water intake pipes for one lobster plant will be necessary. The costs have been assessed by the International Passamaquoddy Engineering Board at $450,000.

The predicted loss of clam supplies will create an excess of clam-processing capacity in the Canadian part of the Quoddy Region. More than one-half of the Charlotte County clam supplies from 1948 to 1957 were obtained from the proposed high pool. There is little reason to expect a change in the pattern of landings in the remainder of Charlotte County sufficient to compensate for this loss. The equipment used by clam processors is specialized and not suited to alternative uses. Assuming, therefore, no major change in clam supplies and in fishing intensity in the section of Charlotte County lying outside the proposed dam sites, it is estimated that about one-half of the existing clam-processing facilities will fall into disuse after the dams are built. Data on investment, employment, and income in clam-processing plants were not provided for inclusion in this report. However, it is believed that the capital which would be disengaged would not exceed $100,000.

RECAPITULATION

Approximate present oceanographic conditions

			High pool	Low pool	Outside
Levels (feet)	Mean level (sea)		0	0	0
	Mean range (spring & neap)		$\frac{+10}{-10}$ 20	$\frac{+9\text{-}1/2}{-9\text{-}1/2}$ 19	$\frac{+9}{-9}$ 18
	Min. max. elevation (spring range)		-14 to +14	-13 to +13	-13 to +13
Currents	Tidal (feet per second)		<1 to 8	<1 to 8	<1 to 6
	Non-tidal (miles per day)		Mostly <2	Mostly <2	Variable to 10
Temperature (degrees Fahrenheit)	Surface	Mean	45	45	45
		Range	32 to 57	32 to 55	34 to 54
	Deep	Mean	45	45	45
		Range	34 to 54	34 to 55	36 to 52
Salinity (parts per thousand)	Surface	Mean	31	32	32
		Range	24 to 32	29 to 33	30 to 33
	Deep	Mean	32	32	32
		Range	31 to 33	31 to 33	31 to 33

Probable oceanographic conditions after the dams are installed

			High pool	Low pool	Outside
Levels (feet)	Mean level		+6	-5	0
	Mean range		4	8	18
	Min. max. elevation		+3 to +11	-11 to 0	-13 to +13
Currents	Gates opened		as present	as present	as present
	Gates closed		speeds markedly reduced; flow toward Western Passage	speeds markedly reduced; flow spreads from turbines	speeds markedly reduced in immediate area; slight increase further away
Temperature (degrees Fahrenheit)	Surface	Mean	little change	little change	Little change except in immediate area where somewhat greater seasonal variation will occur.
		Range	<32 to 66	<32 to 61	
	Deep	Mean	little change	little change	
		Range	32 to 55	32 to 59	
Salinity (parts per thousand)	Surface	Mean	<25	approximately 25	
		Range	<20 to <30	<20 to approximately 30	
	Deep	Range	29 to 33	28 to 32	

Fisheries of the Quoddy Region - Present and Predicted
(average annual landings (pounds) within the period 1937 to 1958

	Present			Predicted
	High pool	Low pool	Outside	Quoddy Region
Species				
Herring	16,800,000	3,400,000	29,800,000	No change
Lobsters	71,250	30,750	286,000	Slight improvement inside dams. No change outside.
Groundfish	225,000	1,900,000	4,000,000	Substantial decrease inside dams. Compensating increase outside.
Clams (meats)	500,000	250,000	500,000	Drastic decrease inside dams. No change outside.
Scallops (meats)	31,000	30,000	31,000	Marked improvement inside dams. No change outside.
Alewives	---	270,000	---	No change
Smelt	500	9,000	---	Slight improvement
Salmon	100	600	---	No change
Others	---	18,200	---	Slight decrease

Economic evaluation of effects of the Passamaquoddy power project on the fisheries of the area

Species	Costs			Annual benefits
	Capital investment	Annual Maintenance	Annual income loss[a/]	
	$			
Herring				
Weir destruction	33,000	---	--- ---	---
Weir alteration	96,000	---	---	---
Weir maintenance	---	10,000	---	---
Teredo damage	---	Indeterminate	---	---
Ice damage	---	Indeterminate	---	---
Lobsters	450,000[b/]	---	---	Slight
Groundfish	---	---	3,000	---
Clams	100,000	---	104,000 (10 yr)	---
Scallops	---	---	---	14,000
Anadromous	3,000,000[b/]	---	---	Slight
Grand total	3,679,000	10,000	107,000	14,000
Total for Canada	663,000	8,000	87,000	12,000
Total for United States	16,000	2,000	20,000	2,000
Common to both countries	3,000,000	---	---	---

a/ In terms of landed fish values to fishermen.

b/ These are preliminary estimates and probably will differ from the detailed International Passamaquoddy Engineering Board estimates.

Summary

On August 2, 1956, the Governments of Canada and the United States referred to the International Joint Commission the responsibility for an investigation to determine the feasibility, desirability, and cost of developing hydroelectric power in Passamaquoddy and Cobscook Bays from tidal forces. On October 3, 1956, an International Passamaquoddy Fisheries Board was established and was given the following reference: "to study specifically the effects which the construction, maintenance, and operation of the tidal power structure proposed might have upon the fisheries in the Area" (cf. I.J.C. Docket 72, October 3, 1956).

A research committee composed of Canadian and United States scientists carried out oceanographic, biologic, and economic investigations in the Passamaquoddy area of southern New Brunswick and eastern Maine. Most of the work was done in the Quoddy Region which includes all of the area inside the line from Point Lepreau, N. B., to Northern Head, Grand Manan, N. B., thence to West Quoddy Head, Maine. The results of the investigations provide a basis for predicting the effects of the project on the fisheries.

It is expected that the construction of dams will change the oceanographic features of the Quoddy Region. Major changes are anticipated inside Passamaquoddy and Cobscook Bays and immediately outside the dams. Effects outside the Head Harbour-Bliss Island line will likely be insignificant.

The mean water level of Passamaquoddy Bay will be raised about 6 feet while the mean level of Cobscook Bay will be lowered about 5 feet. The mean "tidal" range in the high pool and low pool will be reduced to approximately 4 feet and 8 feet respectively. The tidal range of the Bay of Fundy may increase approximately 1 percent with a maximum increase at the head of this Bay of less than 1 foot.

Current patterns in Passamaquoddy and Cobscook Bays and in the approaches will be altered markedly since the emptying and filling gates will be closed for about 9 and $9\frac{1}{2}$ hours respectively during each tidal cycle of $12\frac{1}{2}$ hours. When the gates are open, velocities in most areas should be only slightly lower than at present. The residual counterclockwise circulation in Passamaquoddy Bay will likely be more pronounced. Tidal streams in the outer Quoddy Region will probably be altered by not more than 20 percent. No change in nontidal circulation is anticipated for the Bay of Fundy.

Reduced velocities in Passamaquoddy and Cobscook Bays will result in decreased vertical mixing, giving rise to increased stratification and hence to greater seasonal variations in surface-water temperature. The summer maximum is likely to be in the vicinity of 68° F. while in winter an ice cover is expected over part of the Bays. Outside, little change is expected adjacent to the emptying and filling gates where there will be slightly greater seasonal variation.

Mean surface salinities for both pools will be lowered but bottom salinities are likely to be altered only slightly. It is doubtful if fresh water will penetrate below 30 to 50 feet. Flushing time is expected to increase substantially. Outside, no significant change is expected except near the emptying gates where there will be a slight reduction in salinity.

Oxygen concentrations of the deep water inside the dams may be lowered somewhat, especially during periods of maximum fresh water discharge. However, it is unlikely to fall below 50 percent saturation.

The herring population is produced outside the Quoddy Region, probably off southwest Nova Scotia. The general abundance of herring in the Bay of Fundy and the Gulf of Maine is unlikely to be affected.

Echo-sounder records show that a large proportion of herring are in the open waters of Passamaquoddy Bay where no fishing takes place. Tagging experiments show that herring move freely throughout the Quoddy Region during the fishing season.

Since there are unlikely to be any significant changes in oceanographic conditions outside the dams, herring should arrive in this area as before. Little change is expected in current velocities in the approaches to the filling gates when open. Because velocities are well above the maximum sustained swimming speed of herring, the fish will be carried through the filling gates. Since the filling gates are open for about 6 hours each day, movement of herring into Passamaquoddy Bay is expected to be delayed. This is also true for Cobscook Bay where entry will be chiefly through turbines. Although the rate at which herring accumulate will be slower, there should be no reduction in overall abundance inside the Bays.

Predicted changes in temperatures and salinities are expected to make the areas inside the dams no less favorable for herring except in isolated areas where high temperatures and low salinities may cause some mortality. Predicted pressures and rates of pressure change between the turbine intakes and exits are within limits that herring can withstand.

No relation between herring landings and various meteorological and oceanographic conditions including surface drift, river discharge, wind speed and direction, zooplankton, temperatures, and salinities is apparent.

Long-term statistics of herring landings show year-to-year variations in individual weir catches and in total catches in various parts of the Quoddy Region. These are of far greater magnitude than the changes that can be forecast as resulting from the dams.

No measurable change in groundfish landings in the Quoddy Region is anticipated, but a change in species composition of the fraction of the catch taken inside the dams is expected. Inside the dams, winter flounder fisheries may increase while haddock and pollock fisheries may be greatly reduced. It is expected that clam fisheries will be greatly reduced for a period of 10 years and then become re-established at a lower level of production. Scallop stocks should increase substantially. Inside the dams, a modest increase in production of lobsters is anticipated. Conditions for anadromous species such as Atlantic salmon and alewives may be improved. Smelt, shad, and sea-run trout stocks should increase. Striped bass and tomcod thrive in areas where conditions of temperature and salinity are similar to those predicted for Passamaquoddy and Cobscook Bays. Some reduction is expected in the availability of marine worms and rockweed.

Six existing herring weir sites will be eliminated by the construction of dams. Other weirs must be relocated or altered to suit the new oceanographic environment. Weir stakes and nets will have to be increased in size to suit new water levels. The resultant fixed costs are estimated at $129,000. Wood borer activity is expected to increase. Ice will cause some damage to weir materials during the winter. The annual cost of weir operations will rise approximately $10,000. It is conceivable that weir owners may discontinue their investments in weirs inside the dams. A shift to other methods of fishing could be expected to maintain the fishery, at least at its present level.

Lobster fishermen are not expected to be adversely affected, but physical damages due to relocation of lobster pounds, refrigeration of water, or extension of intake pipes are expected to cost $450,000. Changes in the clam fishery may result in a loss of capital investment in plants valued at $100,000 and an annual loss in primary production of $104,000 for 10 years. The disappearance of some groundfish from inside the dams will result in an annual loss of approximately $3,000.

The installation of fish-passage facilities required for anadromous species was estimated by fisheries engineers to cost $3.0 million.

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